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NOVEMBER 1978

BIOTECHNOLOGY, RESEARCH & DEVELOPMENT DIVISION

LOCKHEED MISSILES & SPACE COMPANY, INC.

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ABSTRACT

This report describes the activities involved in the design, development, and test of a preprototype vapor compression distillation water recovery subsystem. This subsystem, part of a larger regenerative life support evaluation system, is designed to recover usable water from urine, urinal rinse water, and concentrated shower and laundry brine collected from three space vehicle crewmen for a period of 180 days without resupply.

Details of Preliminary design and testing as well as component developments are included. Trade studies, considerations leading to concept selections,problems encountered, and test data are also presented. The rework of existing hardware, subsystem development including computer programs, assembly verification, and comprehensive baseline test results are discussed.

Prime contractor for this program was Lockheed Missiles & Space Company, Sunnyvale, California. The issuing organization was NASA Lyndon B. Johnson Space Center, Houston, Texas.

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DEFINITIONS

COD	Chemical oxygen demand
JSC	Johnson Space Center
LMSC	Lockheed Missiles & Space Company
MDV	Maintenance disconnect valve
PMU	Pretreat metering unit
PPM	Parts per million
RLSE	Regenerative life support evaluation
RO	Reverse osmosis
SI	International System of Units
SSP	Space station prototype
SWW	Soiled wash water
TC	Total carbon
TOC	Total organic carbon
VCD	Vapor compression distillation
μ	Micro (a submultiple of SI Units = 10^{-6})

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Section 1
PROGRAM DESCRIPTION

This section discusses the findings of the program including summary, results, conclusions, and recommendations. It also introduces the reader to the objectives and background of the efforts conducted in this program.

1.1 Findings

Development of a preprototype Vapor Compression Distillation water recovery subsystem (VCD) was undertaken in September 1976 by the Biotechnology Department, Research and Development Division of Lockheed Missiles & Space Company, Sunnyvale, California. This development was the consequence of efforts conducted under Contract NAS 9-15136 issued by the NASA Lyndon B. Johnson Space Center. The VCD is part of a larger system designated Regenerative Life Support Evaluation (RLSE). The integrated RLSE would eventually be tested in-house by NASA and provide the basis for prototype and flight hardware. Spacelab was designated as the probable flight vehicle.

A working VCD resultant from previous contractual efforts NAS 9-10273, NAS 9-13714, and NAS 9-14234 was made available to LMSC. Several components of this VCD were known to have problems and were scheduled to be redesigned. A familiarization test was conducted to quantify these problems and in so doing others were discerned. Analyses of failure modes developed the need for additional components. After consolidating all this information, the VCD was disassembled and component developments undertaken. The VCD module was reconfigured to be compatible with the Spacelab racking concept. As components were developed, they were bench tested and installed in the module. Verification testing of the preprototype VCD proved subsystem viability. A baseline test processing various waste stocks was conducted to provide a data base against which the results of zero gravity tests may be compared. Development of a subsystem computer model provides a method of analyzing the fundamental operation of the process.

The results of this contractual effort culminated in production of a preprototype VCD capable of processing pretreated urine and flush water, pretreated hyperfiltration brine, or mixtures of the two. It showed the subsystem to be capable of reliable, unattended zero gravity operation. It demonstrated that inflight maintenance within the constraints of Spacelab are achievable.

Specific results attained are:

1. Improvement of the compressor drive motor by development of a small light weight efficient compressor drive system characterized by:
   - a) Deletion of four previously existing ball bearings and a magnetic coupling.
   - b) Much shorter and more compact volume.
   - c) Higher starting and stall torques.
   - d) Elimination of coupling breakaway problem.
   - e) Use of stronger, more durable rare earth magnetic material.
   - f) Lighter weight.
   - g) Increase in efficiency from 50.5% to 72% with potential for increase to 90%.
2. Reduction of internal mechanical losses in the distillation unit by:
   - a) Development of a more efficient single belt centrifuge drive system.
   - b) Elimination of demister rubbing on the centrifuge stationary shaft.
3. Enhancement of distillation unit service life by development of corrosion protection for:
   - a) Compressor lobes, gears, and bearings.
   - b) Speed sensor
   - c) Liquid level sensor
   - d) Evaporator temperature sensor
   - e) Boiler and condenser fabricated joints.

4. Increase in subsystem performance by elimination of inleak pathways through excessive vacuum penetrations in the still.

5. Reduction of servicing requirements by provision for relubrication of compressor gears while operating.

6. Development of a centrifuge speed sensor which :

   a) Is removable while running.

   b) Provides a strong signal immune to electromagnetic interference.

   c) Is corrosion proof.

   d) Is relatively immune to clearances of moving parts.

7. Reduction of service down time by development of a more easily serviced distillation unit characterized by:

   a) Axial restraint of the assembly so moving parts may be checked for proper clearances prior to installation of the vacuum shell.

   b) Easily removable Liquid Level Sensor and Boiler Temperature Sensor.

8. Reduction of spashing and carryover fouling of condenser by addition of a recycle pickup splash control barrier.

9. Prevention of centrifuge bearing lubricant washout by vapor flow path diversion.

10. Reduction in amount of plumbing required by consolidation of all still fluid interfaces to one central hub location.

11. Increased compressor efficiency by:

    a) Removal of volumetric efficiency degrading blow back cavities in rotors.

    b) Elimination of relief valve opening.

12. Incorporation of an energy saving operational technique utilizing daily recycling through the "Low Solids" waste tank.

13. Rapid assessment of off-condition VCD performance provided by development of a computer program and analytic model of the fundamental operation of VCD. This program includes over 200 variables and predicts:

    a) Overall performance

    b) Steady state thermal equilbria

    c) Transient thermal regimes

14. Increase in service life and changeout capability provided by development of a long lived low maintenance peristaltic fluids pump characterized by:

    a) Low power consumption.

    b) High volumetric efficiency.

    c) Provision for tube lubrication while running.

    d) Smaller lighter weight maintenance disconnect valves.

    e) Greater flow rates.

15. A greater understanding of purging requirements attained by development and analysis of several alternate purging systems.

16. Validation of safe effective waste stock pretreatments for both urine and R.O. Brine.

17. Automation of pretreat dispensing in conjunction with the waste collection station.

18. Elimination of the need for recycle tank filtration.

19. Development of a corrosion prevention greaseplate for protection of normally corrosive metals in pretreated wastestock.

20. Improvement in subsystem control by development of:

    a) A long lived, responsive, on-line pH sensor in the recycle liquor.

    b) An effective boiler film thickness sensor with automatic control features.

    c) Dual precision boiler temperature sensors with automatic control features.

21. Establishment of automatic VCD operation by enlargement of controller mode states. Elimination of unwanted shutdowns due to logic lockup.

22. Enhancement of data taking and knowledge of subsystem status by development of an easily understood display.

23. Elimination of waste tank bladder failures by development of a metal bellows tank.

The VCD resulting from this contractual effort has overcome most of the original shortcomings that existed in the SSP configuration. The choice of a permanent magnet brushless DC compressor drive motor was correct. The efficiency was substantially increased, and the potential for more increases exists. Internal changes in the distillation unit were beneficial in that many sources of rubbing, complicated assembly techniques, vacuum leaks, short service life, and unreliable instrumentation were eliminated. The failure of liquid level and boiler temperature circuits was attributed to faulty potting of the internal wiring connector. The addition of a desuperheater is not warranted. Condensate production increased without it, and the compressor head rise was greatly reduced. Passive thermal control of the distillation unit results in lengthy thermal transients, and non-optimum operating conditions through much of the solids accumulation cycle.

Computer program predictions dealing with high quantity energy conservative systems including 200 variables are vulnerable to very small external influences. Some choices were made based on assumed waste input profiles and mission data.

For future investigations a number of areas should be examined:

1. The inability to achieve normal drydown seems to be related to a design change of vapor routing from the compressor to the condenser accomplished during SSP modification. In contract NAS 9-9191, advantage was taken of vapor kinetic energy exiting the compressor to deflect it into the condenser. In SSP, the vapor stream was stagnated and flow onto condensing surfaces effected by pressure differences. The effect of the design change did not become apparent until baseline testing occurred in this program. Future designs should reinstate this flow routing.
2. Purging of non-condensibles should be treated solely on the merits of the non-condensible pumping problem. It was revealed that a very small amount of non-condensibles in the condenser could cause a large change in heat transfer even when the condenser was effectively at water saturation temperature and pressure. It is insufficient to only be able to pump the condenser down to operating vacuum. The pump capacity must be able to extract non-condensibles at the partial pressure they possess within the condenser. The oil sealed vane pump is capable of this requirement. More study of the purging requirement is needed.

3. Operation of the liquids pump at cabin pressure should be investigated. Deletion of the need for vacuum reflation of pump tubing would lead to a lighter weight design and the possibility of extending gearmotor life. Should case vacuum be deemed necessary, externalizing the gearmotor should still be considered by utilizing a dynamic shaft seal.
4. More specific vehicle and mission requirements are needed to settle waste input and operating time schedules.
5. A general weight reduction effort should be instructed.
6. If more control functions are to be added, consideration should be given to microprocessor control. For development purposes, manual control would be helpful.

1.2 Introduction

The primary objective of this effort was to develop a preprototype vapor compression distillation water recovery subsystem capable of processing urine, urinal rinse water, and shower and laundry concentrated brine of three crewmen for a period of 180 days without resupply.

Secondary objectives include:

a) Low specific power consumption
b) High production rates
c) Automatic operation
d) Reliable long-lived components
e) Minimum maintenance
f) Minimum spares

To this end, specific objectives were outlined.

a) Develop a low power, high performance purge pump
b) Develop a low power, high performance liquids pump
c) Develop a waste water treatment unit
d) Develop a reliable waste tank
e) Develop a reliable electronic controller
f) Develop a pretreat solution storage and dispensing unit
g) Develop a custom compressor drive motor
h) Develop a VCD module
i) Test and document module performance.
j) Develop method of corrosion protection
k) Develop improved instrumentation specifically for zero-g operation
l) Develop a display panel
m) Develop passive thermal control to reduce the thermal startup transient.

The VCD Module developed by Chemtric, Inc. under subcontract to UAC Hamilton Standard Div. was described in the final report requirements of Contracts NAS 9-13714 and NAS 9-14234. Subsequent to that effort the hardware was delivered to NASA JSC/EC3 Branch Houston, Texas. There it underwent miscellaneous tests culminating in a 30 day operational test. During this testing period, a number of deficiencies were noted and formed the basis for this contract. Additionally, plans were developed to integrate all the water and atmospheric control subsystems into a Regenerative Life Support Evaluation (RLSE) for the Spacelab. Consequently Contract NAS 9-15136 was let to accomplish the objectives previously stated and to reconfigure the VCD subsystem to be compatible with RLSE. The Chemtric Corporation had disbanded by this time, so an industry wide competition seeking new contractors was instituted.

The Biotechnology Department of the Research and Development Division of the Lockheed Missiles & Space Company was awarded this contract in September 1976 and formed a subcontractual relationship with D. K. Precision, Inc. of Franklin Park, Illinois. D. K. Precision was involved in the fabrication of VCD components for Chemtric, and had on its staff, either in a direct or consulting basis, several of the key personnel from Chemtric who had participated in that organization's VCD programs.

All the efforts summarized in this report was monitored by D. Fricks and W. Reveley of the Environmental Control and Life Support Systems Branch, Crew Systems Division, Engineering and Development Directorate, NASA Lyndon B. Johnson Space Center, Houston, Texas. P. Nuccio and D. Knapp of D. K. Precision, Inc. Franklin Park, Illinois made major contributions in design, test, and fabrication of the vapor compression still, peristaltic pumps, and system considerations.

K. Johnson served as program manager at LMSC. Other major contributors at LMSC are: R. Jagow and T. Olcott, for administrative and technical support, R. Luce for electronic design, and P. Wagner for analytical support.

Section 2

PRELIMINARY DESIGN AND TESTING

2.1 Preliminary Design

Preliminary design was truncated in this effort due to the amount of hardware and technology existant. Resolution of most questions were accomplished in the performance of component developments. Discussions of these efforts are reported herein.

2.2 Testing

Testing at JSC culminating in the 30-day operational test of the SSP VCD exposed most of the problem areas addressed in this contractual effort. After the module was transferred to LMSC, a familiarization test was scheduled. The test would acquaint LMSC personnel with the VCD, attempt to recreate the difficulties experienced in the 30-day operational test, and establish whether or not a filter in the recycle tank is needed. To this end a small acrylic recycle tank was constructed to accelerate solids concentration in the recycle loop, and to provide visual information on the character of the recycle liquor. The resultant tank has a volume of $2153 \mu m^3$ ($2153 \times 10^{-6} m^3$) (131.39 in^3). Putnam[1] indicates raw urine is 2.48 to 3.71% dissolved solids by weight. These solids are further diluted by the addition of flush water and chemical pretreatment. The chemical pretreatment formulation is as follows:

Component Chemical	Manufacturer	Concentration % by Weight	Grams per 260 ml micturation
Biopal VRO-20	General Aniline & Film Corp.	29.3%	0.659
Sulfuric Acid (95-98% purity)	Com'l	15.1%	0.340
Antifoam A	Dow Corning Corp.	0.1%	0.002
Antifoam H-10	Dow Corning Corp.	5.7%	0.128
Distilled Water	Com'l	49.8%	1.121
		100.0%	2.250

[1] David F. Putnam, Composition and Concentrative Properties of Human Urine (Huntington Beach, Ca.: McDonnell Douglas Astronautics Co., 1970), p. 5.

The pretreatment formulation was evolved from parametric tests conducted under contract NAS 9-9191. Systems considerations dictated use of a specific quantity of pretreatment chemical with each micturation. The nominal micturation volume is $260 \mu m^3$ (260 ml). The amount of pretreatment chemical used per micturation was 2.25 g. Also from previous contractual efforts the flush water allocation used for each micturation is $150 \mu m^3$ (150 ml).

When $260 \mu m^3$ urine is mixed with $150 \mu m^3$ flush water, the dissolved solids are diluted to 1.57-2.35%. On this basis, it was expected to achieve 50% solids in the recycle liquor after processing 57.5 kg (126.6 lb).

A total of 11 runs were made. The first being a water calibration run. Thereafter pretreated urine/flush water compounded per the above ratio was used as waste stock. Figure 2-1 shows the progress of recycle solids buildup. Considerable divergence of actual solids concentration buildup vs predicted occurred. The explanation for this was accepted as typical precipitation occurring at the 30% point. Water recovery was minimal in the 80% region mostly.

The condensate production rate shown in Figure 2-2 seemed normal. At no time was there any problem with pH control of the recycle liquors. Figure 2-3 shows an almost constant pH = 2.8. Figure 2-4 shows the relationships between process temperature as exemplified by condenser pressure, recycle solids ratio, and production rate. Four plots show the effect of the thermal transient on production for 4 different recycle solids conditions.

The test terminated when a recycle tube failure in the liquids pump allowed a large amount of feedstock to enter the boiler and grossly dilute the recycle liquor. A recurrent condition was the inability to achieve normal drydown. Upon entry to the drydown mode, the compressor delta

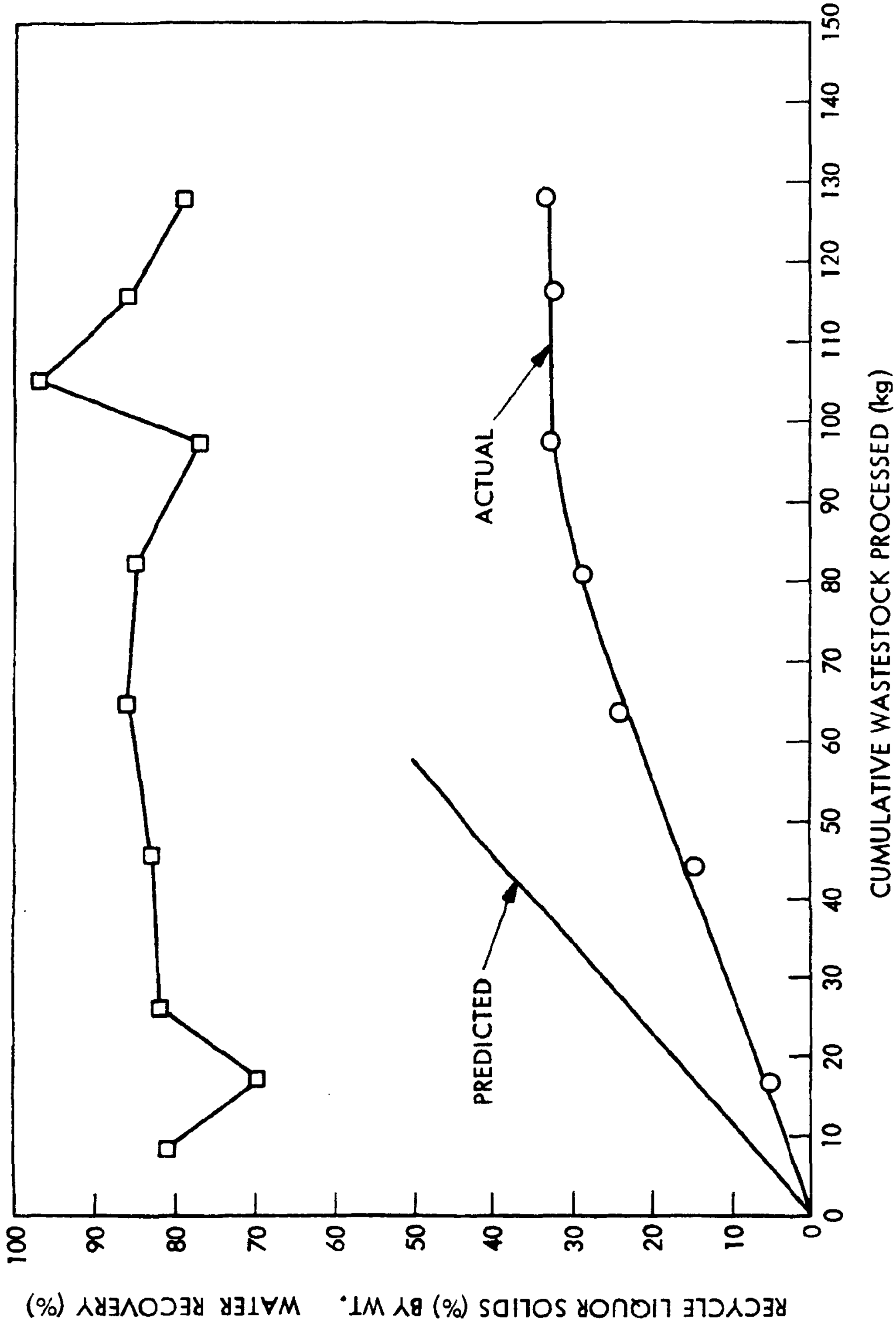


Figure 2-1 Water Recovery and Solids Concentration Rate

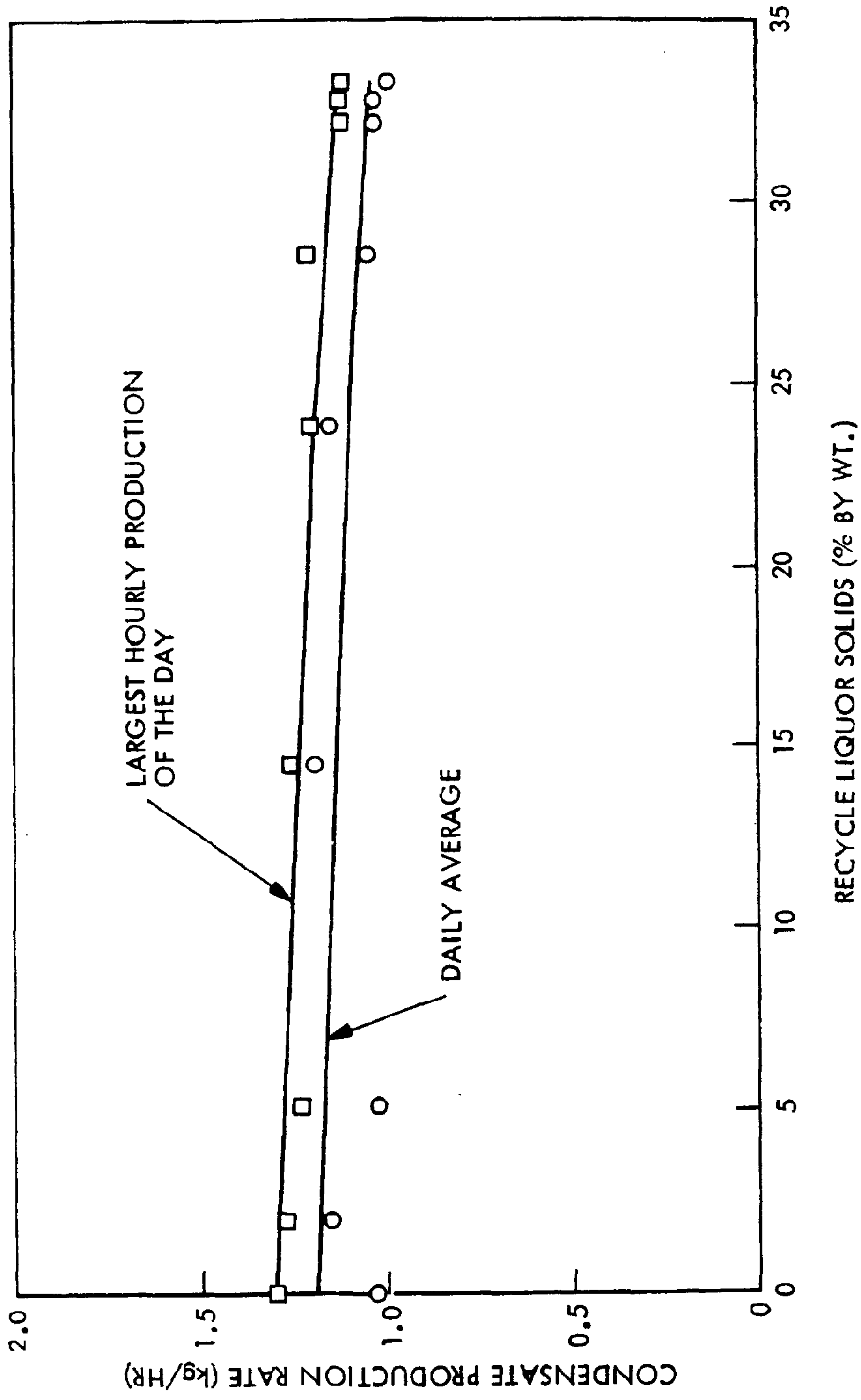


Figure 2-2 Familiarization Test Condensate Production

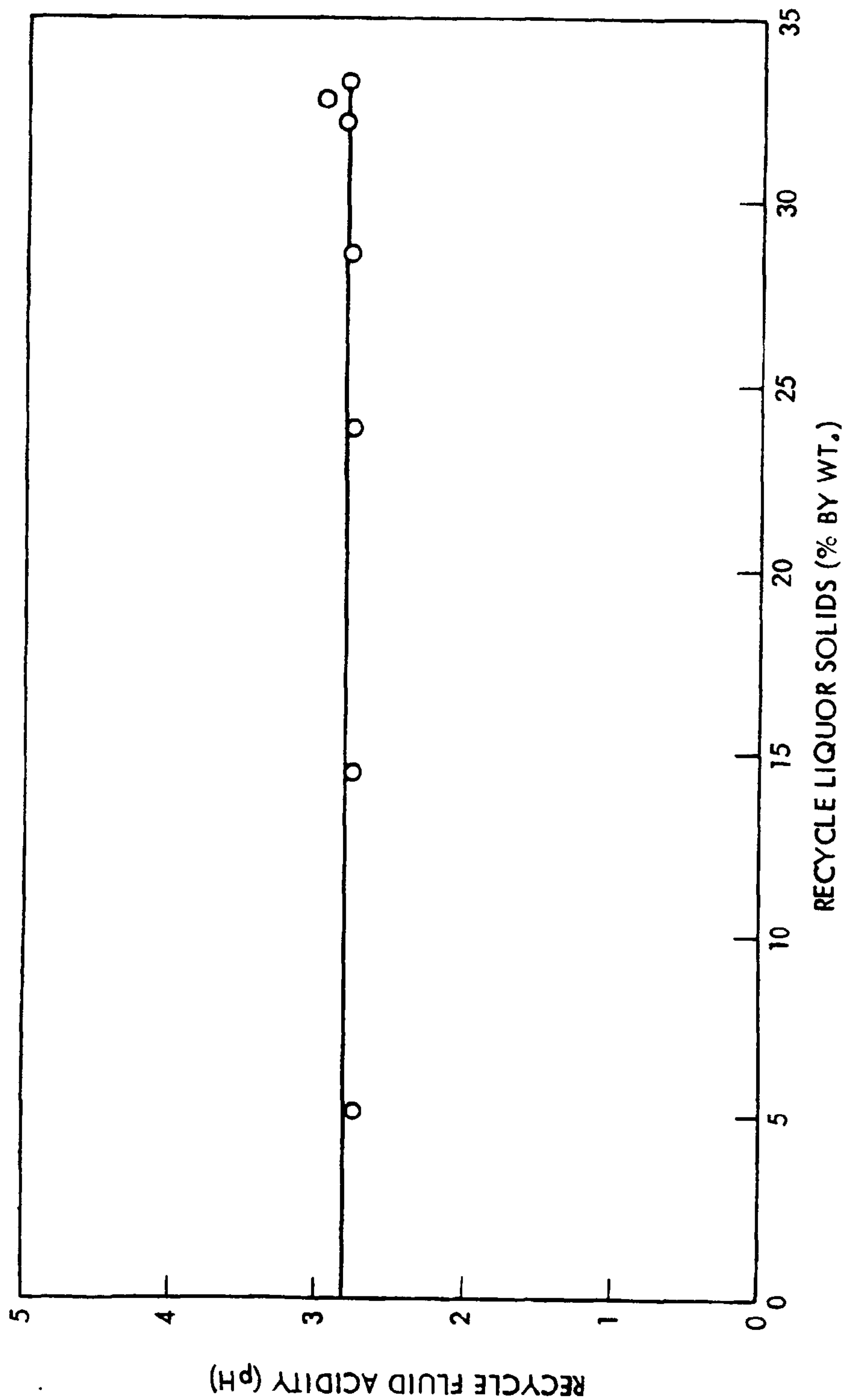


Figure 2-3 Familiarization Test Recycle Liquor Acidity

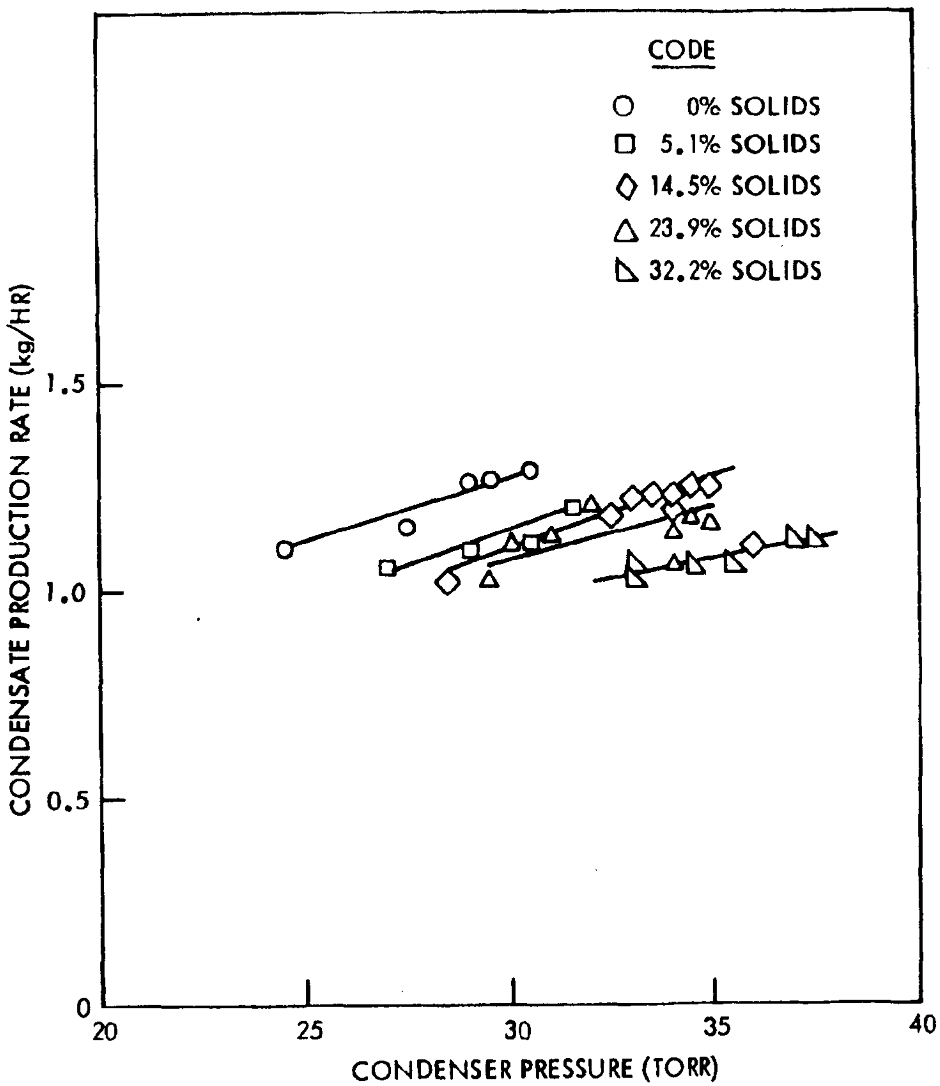


Figure 2-4 Condensate Production Variation with Condenser Pressure and Recycle Solids

pressure would climb a small amount, then stabilize. The operating mode finally adopted was to manually divert condensate from the subsystem after 45 minutes of drydown had taken place. Then, when the boiler became dry, a high compressor delta pressure indicated dryness and shutdown could take place. However a small amount of recycle solids was trapped in the evaporator, and when the evaporator eventually went dry, it became caked on the boiler surface. Subsequent disassembly revealed a caked deposition all over the boiler of about 0.81 mm (0.032 in) thickness.

Unfortunately, a complete solids scan had not been accomplished when the test terminated. However, preliminary indications were that a filter in the recycle tank was unnecessary. Further testing of this aspect was planned for verification and baseline testing.

As inspection of the boiler found considerable warpage and out of roundness. A general bulging area was calculated to have contained possibly $200 \mu m^3$ of fluid. If a pocket of fluid were unable to communicate with the dry-down holes at the base of the film thickness control dam, then the vapor would be locked in a closed loop of evaporation, condensation, and refeed. In order for a planned drydown to occur, the contents of the boiler must eventually leave via the recycle out pathway. It was planned at that point to take stronger measures during distillation unit modifications to insure boiler cylindricity.

Section 3
COMPONENT DEVELOPMENT

This section describes the activity by which each component of the VCD was modified, or renewed. Certain development tasks were contractually required such as the pretreatment metering unit, controller logic, waste tank, compressor drive motor, corrosion protection, instrumentation, control panel, insulation, pH meter, purge pump, fluid pump, and lubricant survey. Other developments were the result of opportunities, and alternatives which arose in the course of conducting such an innovative program.

3.1 Purge Pump Development

Purging of the vapor compression distillation unit is necessary primarily to remove non-condensible gases which impede the exchange of latent heat. Secondarily, by evacuating the boiler and condenser the phase changes occur at lower temperatures. Low temperature distillation greatly reduces thermal decomposition and co-distillation of contaminants, as well as eliminating the need for addition of heat to maintain a warm processor.

During the first decade of VCD development, the purging requirement was met by venting the distillation unit to space vacuum. All development testing was performed with a conventional laboratory vacuum pump simulating the anticipated overboard vent. From previous testing, it has been determined that a purging rate resulting in water vapor extraction of 1% of the total output is necessary to remove non-condensible gases. Reçent long-duration flights have confirmed that any material vented overboard becomes part of an atmosphere cloud which forms around the spacecraft. Among other detrimental effects the cloud interferes with light transmission. Recovery of the purge water is accomplished by purging with a pump which discharges the moisture to the cabin for ultimate recovery by the cabin dehumidifier.

Presently developed vacuum-generating technology in the ranges of pressure ratio and flow rate applicable to VCD is typically gravity-dependent or very inefficient relative to the rate of thermodynamic work done. The first VCD system built with a self-contained purging pump was the SSP VCD system. A gravity-independent two-stage piston pump, originally developed as an airborne radar waveguide vacuum pump was adapted to the VCD application. The power requirement was known to be very high, a filter was necessary to protect the valves, and noise generation was found to be so severe that an acoustic muffler chamber was built around the pump and motor. These severe limitations notwithstanding, an integration of a self-contained vacuum source with a VCD system was achieved for the SSP.

The most significant requirements of a purge pump are that it operate over a large pressure ratio, that power consumption is low, and, that pump longevity be at least 180 days for an on-line purge pump. In keeping with the low-power-consumption characteristic of VCD an arbitrarily-established limit of 50 watts has been set.

The first two requirements are met best by a peristaltic-type pump. All of the many varieties of peristaltic pumps operate without valves and without clearance volumes. Theoretically they have an infinite compression ratio. Peristaltic pumps are inherently efficient relative to piston and valve pumps, especially at the low specific speeds typical of a VCD application. Longevity of conventional peristaltic tubing pumps however is inadequate primarily because gaseous media provides inadequate cooling of the tubing, and in conventional tubing pumps no other heat-sinking path is adequate to prevent the tubing from over-heating

An early investigation of the problem of short peristaltic tubing life was made with one candidate solution. Recently a mutation of the conventional tubing peristaltic pump became available commercially. In that variation, named "toroidal piston pump" the eccentric roller is replaced by a nutating disk. The disk applies peristaltic compression axially rather than radially as in a conventional pump. The peristaltic member is a membrane located in a single plane perpendicular to the axis of disk rotation, and covering a stationary toroidal-shaped groove. With that configuration, the primary advantages of peristaltic pumps are retained: the compression ratio is infinitely high, no large masses are accelerated, and no large friction forces are to be overcome. The major advantage is that the membrane is stressed only in tension as it is alternately driven into, and withdrawn from the toroidal groove. Thus the 180° corner bends which occur in conventional circular tubing as it is compressed are eliminated. The 180° bends are the location where tubing failure most often occurs by material fatigue. The 180° bends are also the major cause of internal heat generation in the tubing material.

In view of the significant life advantage inherent to the toroidal piston pump, a production pump was purchased for evaluation of both performance and life in the VCD application. Initial tests showed that ultimate vacuum generated in a closed flask was only approximately one-half atmosphere. Subsequent disassembly disclosed that machining accuracy of the toroidal groove was not sufficiently controlled to maintain a gas seal with the membrane. The inventor and builder of that pump was consulted and the decision made to improve the groove machining. After shop modifications a significant, but still inadequate improvement in ultimate pressure was measured.

Lower ultimate pressures were measured when the pump was wetted prior to a test run, indicating that the membrane-to-groove seal was not effective enough to prevent back-leakage of gas in the absence of a viscous filler. A coating of stop cock grease was applied to the groove and diaphragm, and tests were re-run. An ultimate pressure of 17.33 kNm^{-2} abs. (130 torr) was achieved. It was concluded that the full potential of the infinite compression ratio pump could be realized, but would be costly. For production pumps, groove machining is performed on a tape-controlled milling machine. The tape program is written in rather coarse increments, and, to reduce costs, the entire groove is machined in one pass of the cutter. Finer increments and multipasses would improve smoothness and reduce tool deformation, which would improve groove accuracy both radially and circumferentially. Membrane thickness too, is critical to seal effectiveness. For the production pump the membranes are molded without subsequent machining. Some thickness variation exists around a single membrane, as well as between membranes produced in the same mold.

Concluding that while it is probable that the toroidal piston pump could be made to meet the VCD performance requirements, it would impose a greater risk and be more costly than concentrating upon improving the longevity of a tubing-type peristaltic pump. Consequently, the first approach was to develop an omega-tube peristaltic purge pump.

This pump was intended to incorporate the same design characteristics applied to the liquids pump. A low-cost development model was built to verify those modifications and to obtain final design data for the preprototype pump. The breadboard pump was built around a single large diameter roller. Special emphasis was placed upon the need for cooling the housing with liquid flowing in a passage machined into the housing.

Forced cooling of a peristaltic pump was evaluated by NASA, with only moderate improvements resulting from the effort. Two significant differences between the Lockheed pump and the Randolph pump on which the NASA tests were run, would make housing-forced cooling more effective. First, the tubing would be clamped into the housing. With the all-metallic housing in direct and sustained contact with both tubing and coolant no significant thermal gradient will exist beyond the tubing base surface. Secondly, a single large roller will hold a greater length of tubing against the cooled metal.

With the two-roller Randolph pump the rollers are necessarily smaller, and, more importantly, the heat to be dissipated during each revolution is that generated by two compressions.

Operation of the breadboard pump served two purposes. First, it was used to investigate the thermal cooling requirements of the purge pump. Second, it was used to investigate tube life and power consumption of special tubing formulations. In the first case, the pump was operated at 61 RPM with no coolant for 350 hrs. No thermal problems were encountered. Although the tube did fail, it was not from over temperature. The tubing was Norton formulation R-3603, 12.7 mm (0.50 in.) I.D. x 17.5 mm (0.688 in.) O.D. The failure mode was cracking commencing on the external surfaces of the 180° bends and propagating inward until the tubing was perforated. The cracks were in alignment with the axial direction of the tubing. An interesting effect noted in this test was that axial tube tension was developed at the outlet rather than at the inlet. This is contrary to most laboratory peristaltic pumps and is related to the ratio of casing to roller diameters. It was felt that a more careful design, particularly in the cross sectional configuration of the tubing could extend tube life.

Since the knowledge gained from these tests were directly applicable to concurrent liquids pump efforts, it was decided to rerun the purge pump tubing life tests to validate the tube formulation for the liquids pump. After this point (480 hours) had been achieved, resumption of purge pump design would proceed, and the life test would continue until tube failure occurred.

During steady state distillation the required purge gas flow rate is that necessary to match the rate at which non-condensible volatile gases are stripped from waste liquid. With the present distillation unit there are no dynamic seals, therefore no in-leakage of cabin gas adds to the purging requirement.

During initial start-up the required displacement rate is that which will evacuate the still volume from sea level to operating pressure in approximately one hour. That time limit was established somewhat arbitrarily, but represents a reasonable start-up delay period during which the tankage will accommodate both potable water distribution and waste collection.

Non-condensible gas generation is variable. With urine as the waste liquid, non-condensible generation rate is very probably a strong function of crew metabolism and somewhat a function of diet. During contract NAS 9-9191 Chemtric determined that a net displacement rate of 6.5 mm^3/min (400 in^3/min) maintained adequate control of non-condensible partial pressure over a wide range of operating conditions. At that rate, approximately one percent of the vapor generated in the boiler is extracted with non-condensible gases.

Initial pump-down of a 37 mm^3 (1.3 ft^3) distillation unit from sea level to 266 Nm^{-2} abs. (2 torr) will require 55 minutes at a displacement rate of 6.5 mm^3/min, which was selected as the design rate for the preprototype purge pump. Applying the same relationships delineated for the liquids peristaltic pump the purge pump speed would be: 44.3 RPM for a tube of 12.7 mm (0.5 in.) I.D. and tubing pitch of 483 mm (19 inches).

Most of the power dissipated in a peristaltic pump is that lost in non-reversible compression of the tubing. As with the liquids pump, calculating that loss requires that the tubing material modulus of elasticity and Poisson's ratio be estimated because these values are not known. A better approximation can be made by scaling the empirical data drawn from a liquids pump. With equal motor and transmission efficiency, input (electrical) power is linear with required driving torque and speed. Torque is linear with the number of tubes being compressed, proportional to the cube of tube wall thickness ratio, and linear with pump diameter. Based on the liquids pump in which three tubes are compressed, the tube wall thickness is equal to that in the purge pump, the pitch diameter is 248 mm (9.75 inches), the speed is 17.3 RPM, and 25 watts input are required; the purge pump would require 42 watts.

Reviewing the phenomenon of tube stretch reversal, it is noted that the curve generated by a point on the circumference of a circle (radius a) which rolls without slipping on the inside of a larger circle (radius c) is called a hypocycloid. For $c/a = 4$ the curve has 4 distinct cusps and is called an astroid. As c/a approaches 2 the hypocycloid becomes a straight line. For c/a less than 2, cusps reappear. If one were to plot sequential cusps for $c/a < 2$ it would be seen that the points of contact are in retrograde relative to the eccentricity radius. For $c/a > 2$ the points of contact are in advance of the eccentricity radius. It is the circumferential component of the retrograde or advancing motion which stretches or compresses the tubing. The case to roller ratio (c/a) controls which type of motion it will be.

Most laboratory peristaltic pumps have $c/a > 4$ and experience a tugging of the tubing against the inlet. The breadboard purge pump had a c/a ratio of 0.91 and experienced tugging of tubing against the outlet. The obvious conclusion is that if $c/a = 2$ then tugging would cease. This theory was put to test. The breadboard pump was modified and a test program started. So far the discussion has dealt with idealized inelastic motion. The real case of a roller squeezing a plastic material against a casing is very complex. The effective rolling radius is dependent on many factors including the modulus of elasticity and Poisson's ratio of both tubing, case, and roller as well as the amount of tube squeeze (occlusion) involved. The test did prove the point. No tube tugging was noted against either inlet or outlet. However, tube life was reduced by a factor of 10. The tube failure mode was exactly as before, i.e. external longitudinal cracks at the 180° bends propagating inwards.

At about this same time it was discovered that the tubing supplier had mistakenly supplied food grade tygon tubing for the tests instead of R-3603 formulation as requested. A test of the R-3603 tubing was immediately started and although it lasted six times longer than the food grade tygon it still was unsatisfactory. Apparently the failure mode is insensitive to circumferential tugging and the original plan of a small c/a ratio (large roller) was the best course of action to pursue. This conclusion was supported by test results obtained from the Norton Co. Norton reported extremely long tubing life in the case of a linear peristaltic pump where $c/a = \infty$ (flat case profile). The roller (in this case, a wiper) would periodically squeegee the fluid through the tube in a sweeping motion.

The goal of 180 days (4320 hrs) could still be met by applying observed test data ratios, increasing the size and number of tubes, and reducing pump speed. The breadboard pump was developing 0.038 mm^3 (2.3 in^3) per revolution and based on the design displacement rate of 6.5 mm^3 (400 in^3)/min. would need to operate at 174 RPM. However, increasing the tubes to 25.4 mm (1 in.) I.D. and the number to two, the required pump speed would decrease to 22 RPM. At that speed 5.7 million squeeze cycles would be applied to the tubing. From test data (350 hrs. at 61 RPM) 1,281,000 cycles had been achieved with food grade tygon tubing. Also from test data, a 6 to 1 ratio of tube life was achieved with R-3603 tube compound. The possibility of surpassing the 5.7 million cycle requirement was very real. Increasing the number of tubes would naturally increase pump power and weight. It was decided to continue the R-3603 breadboard pump life test to validate the ongoing liquids pump design and defer the RLSE peristaltic purge pump design until alternate purge pump concepts could be investigated. The life requirement of the preprototype pump was reassessed and set at 90 days (2160 hr.), and maximum power consumption goal set at 50 W.

The approach to alternate purge pump developments was either to adapt a zero-g aerospace quality vacuum pump to VCD, or to convert a one-g high quality commercial pump, which will perform the VCD task, to zero-g capability. Efforts to secure the former were unsuccessful, but three versions of the latter were investigated. They are: 1) an oil sealed pump operating at high temperature, 2) an oil sealed pump operating at low temperature with a condensate separator, and 3) an oilless vane pump.

A small oil sealed vane pump (Model 8802 Sargent-Welch, Vacuum Products Division, Skokie, Illinois) was obtained for test. This pump is 102 mm (4 in.) by 241 mm (9.5 in.) x 130 mm (5.12 in.) in size. It has four oil sealed vanes in a single stage and relies on one-g to separate non-condensibles from the oil. The free air displacement is 25 mm^3 (1525 in^3/ min. Blankoff Pressure is 8 Nm^{-2} abs. (0.06 torr).

The pump housing was wrapped with insulation and the inlet connected to evacuate a large bell jar. Inside the bell jar was placed a beaker of water on a hot plate. Water temperature was sensed with a thermocouple and controlled manually by adjusting the hot plate voltage. Before the water was added, the ultimate pump down capacity of the test set up was measured at 2.13 kNm^{-2} (16 torr) with an air inleak of 332μm^3 (0.332 1)/min. The pump case temperature was 52°C (125°F). Water was added to the beaker and heated to boiling. The boiling rate was adjusted to result in a uniform coating of fine condensation droplets on the inside surface of the bell jar. This was indicative that the atmosphere in the bell jar was saturated. After running for 13.25 hr, 186μm^3 (186 ml) of water was determined to have passed through the pump for an average throughput of 0.23μm^3/min (0.23 ml/min). Other data were:

Average bell jar pressure	4kNm^{-2}	(30 torr)
Average water temperature	29.4°C	(85°F)
Average pump case temp.	82.2°C	(180°F)
Average air leak rate	281μm^3/min	(.281 1/min)

An examination of the pump afterwards revealed some water was retained in the oil, and that the oil was at or above its maximum operating temperature with definite signs of carburization taking place. The Duo Seal oil which is normally used was replaced with Dow Corning DC200-100 silicone oil at the suggestion of the manufacturer. The DC200-100 oil has two beneficial traits. First it can operate at high temperature and second it is non-miscible with water.

Another test of the 8802 pump was conducted. Objectives of this test were to more closely meet VCD conditions, and to raise the pump temperature to 100^{o}C (212^{o}F) to ensure no water entrainment in the pump oil. The free air displacement rate of the pump was reduced by connecting a variable speed motor to a shaft extension of the original motor. The original motor was retained because its bearings also support the pump rotor. Slowing the pump to 1110 RPM produced a free air displacement rate of 7.1 mm^3/min (432 in^3/min). The desired air inleak rate of 0.1 mm^3/min (6 in^3/min) was attempted into the dry bell jar, but a faulty shaft seal caused excessive inleakage. The ultimate vacuum obtained was 2.07 kNm^{-2} abs. (15.5 torr).

A new seal was ordered, but before it arrived, a hot test was run on a wet chamber. Results of this test were:

Free air displacement rate	8.4 mm^3/min. (519 in^3/min)
Air inleak rate	440μm^3/min. (26.8 in^3/min)
Pump case temperature	100^{o}C (212^{o}F)
Bell jar vacuum	2.93 kNm^{-2} abs. (22 torr)
Pump Speed	1375 RPM
Boiling Water Temp.	33.9^{o}C (93^{o}F)

Subsequent pump disassembly revealed no residual water or other defects except for the above mentioned shaft seal.

A reassessment of VCD non-condensible production rate was made based on observations of previous contracts where a 266 Nm^{-2} (2 torr) rise in condenser pressure was noted in a 3 min. period with the purge pump inlet shut off. On the basis of a still volume of 35.39 mm^3 (1.25 ft^3), this pressure rise corresponds to an air inleakage of 2.15 g/hr. or 29μm^3/min. at one atmosphere.

Upon receipt and installation of a new shaft seal, the test was repeated. The results of the test with the new shaft seal installed were:

Blankoff press. (before hot test)	933 Nm^{-2} abs. (7 torr)
Free air displacement rate	6.5 mm^3/min. (397 in^3/min)
Air inleak rate	30μm^3/min. (1.83 in^3/min)
Pump case temp.	100°C (212°F)
Bell jar vacuum	3.47 kNm^{-2} abs. (26 torr)
Pump Speed	1100 RPM
Boiling Water Temp.	32.2°C (90°F)
Water throughput	0.01μm^3/min. (0.6x10^{-3} in^3/min)
Mech power to pump	18W

This test showed that a hot oil sealed vane pump was capable of accomplishing the VCD purging function.

The remaining task was to make it operate in zero-g. The operational method of this pump is to inject oil into the rotor cavity whenever a favorable pressure difference exists between the oil sump and rotor cavity. Centrifugal weights and a check valve control the inflow of oil to a specific point in the compression cycle. The oil is distributed through passages to seal both the sides and tips of the vanes against the rotor housing. Surplus oil mixes with the non-condensibles and water vapors being pumped. The mixture is discharged through a reed check valve out of the rotor housing and into the oil sump below oil level. The non-condensibles and water vapors bubble up through the oil and leave the pump at its outlet connection. The oil droplets are retained by the oil in the sump effecting a one-g two-phase flow separation.

In zero-g the oil sump would be removed and replaced by an accumulator. The accumulator would be connected to provide sealing oil to the injection port of the rotor housing. The accumulator would be constantly refilled by receiving the oil output of a small centrifugal phase separator. The input to the phase separator would be the two phase mixture of oil droplets and non-condensibles and water vapor exiting the pump. The other output of the phase separator would be the non-condensibles and water vapors. Tests of oil flow at various inlet pressures were conducted to develop a procurement specification for the two phase flow separator. The specification and RFP were circulated to vendors. The resultant proposed design was 63.5 mm (2.5 in) in diameter by 190.5 mm (7.5 in.) long consuming a maximum of 10 W electrical power.

The above described system would discharge superheated water vapor into the cabin for ultimate reclamation by the cabin dehumidifier.

A variation of this system would operate the purge pump at ambient temperature allowing the water vapor to condense as it achieves cabin pressure. The non-condensibles would be separated as described above in a centrifugal two phase flow separator. The water and oil would then be separated by a centrifugal single phase liquid density separator. Usage of DC 200-100 oil would assist in this procedure due to its inherently high non-miscibility with water. Both centrifugal separating stages would be driven by the same motor and share other common elements.

Operating at elevated temperatures and using phase separation, although feasible, was not desirable. A solution to this problem is the dry vane rotary pump. A vendor was located who had developed a small pump for an airborne application which closely fit VCD requirements. A laboratory unit (Model RG19000A Lear Siegler Inc., Romec Div., Elyria, Ohio) was loaned to LMSC for test. This pump is 127 mm (5 in.) by 67.5 mm (2.66 in.) by 58.7 mm (2.31 in.) in size. It has two 4-vane stages directly driven by a double end shafted motor. A crossover pipe connects the two stages in series external to the motor. The free air displacement is 7.37 mm^3/min. (450 in^3/min). Blankoff pressure is 4.8 kNm^{-2} abs. (36 torr).

Initial tests revealed excessive air in-leakage through the motor power wiring grommet. This was ultimately reduced to 20 μm^3/min. (1.22 in^3/min) and when blanked off produced 3.1 kNm^{-2} abs. (23 torr) pressure. The inleak was adjusted upward and a wet test begun. Results were:

Air inleak rate	$40 \mu m^3$/min (2.44 in^3/min)
Bell jar vacuum	4.9 kNm^{-2} abs. (37 torr)
Boiling Water Temp	31.1°C (88°F)
Water throughput	$0.03 \mu m^3$/min ($1.83 \times 10^{-3} in^3$/min)
Electrical power input	80 W

These tests seemed promising, so a specification was created and a quotation requested.

At the critical design review, all purge pump activity was examined including both preprototype and prototype concepts. Total equivalent mass was calculated using a factor of 0.272 kg/W (0.6 lb/W) added to the actual mass. A summary of purge pump information at that time is presented in Table 3-1.

Table 3-1

Comparison of Purge Pump Concepts

Concept	Power (W)	Mass (kg)	Vol (mm^3)	Total Equivalent Mass (kg)
Peristaltic	74	20.0 (44 lb)	24.3 (0.86 ft^3)	40.0 (88 lb)
Oil seal (high temp)	40	6.8 (15 lb)	7.1 (0.25 ft^3)	17.7 (39 lb)
Oil seal (low temp)	41	6.8 (15 lb)	7.1 (0.25 ft^3)	18.2 (40 lb)
Oilless vane	80	1.4 (3 lb)	0.8 (0.03 ft^3)	23.2 (51 lb)

In view of the above characteristics and the design maturities involved, the oilless vane pump concept was selected. A procurement was initiated. Performance improvements over the RG19000A model tested were: reduce the free air displacement to 6.554 mm^3/min. (400 in^3/min), increase vacuum capability, increase corrosion resistance of all elements, and increase life. The major design change was to route all flow from the first stage through the motor housing into the second stage. Sealing of the motor shaft was not considered feasible due to the high speed (11,000 RPM) and quest for low power. Previous units had been operated pumping mixtures of glycol/water and methanol/water through the motor housing.

The manufacturer tested the unit at his facility and reported an ultimate blankoff pressure of 853 Nm^{-2} (6.4 torr), 74 W power consumption, and free air displacement rate of 6.554 mm^3/min. (400 in^3/min). The unit was delivered to LMSC and connected to the wet test stand for round the clock endurance testing. Initial values obtained were: Blankoff pressure 4kNm^{-2} abs. (30.2 torr), power 66 W, inleak 30μm^3/min. (1.83 in^3/min), boiler temperature 23.9°C (75°F). After 49 hours running, one phase of the 3 phase motor stator windings opened. The unit was returned to the vendor for repair. A new stator was fabricated and more stringent waterproofing measures taken. Additional coatings of varnish were vacuum applied and baked. After returning the unit to test, essentially the same performance was attained. The unit was connected to the still for a trial pump down. Ultimate pressure achieved was 2.7 kNm^{-2} abs. (20 torr). Several runs of the VCD were made using a combination of the dry vane pump, mounted on the wet test stand, and a standard lab pump.

The dry vane pump was transferred to the VCD module to reduce induction losses. When not operating VCD, the pump was switched back to the test stand. Power consumption at blankoff conditions had dropped to 55 W by 384 hour of operating time. At 456 hour one of the stator phases again opened. It was returned to vendor for repair. The vendor reported significant corrosion in the motor housing, but little wear in the pump stages. If the electrical open problem is unsolvable, a suggested improvement would be to use a magnetic coupling and remove the motor from the flow stream.

3.2 Liquids Pump Development

The compression distillation process requires a continuous transfer of liquids across an interface with tankage. Three streams must be maintained. They are: 1) waste liquor entering the boiler, 2) concentrated waste liquor leaving the boiler, and 3) distillate leaving the condenser.

A pressure difference exists across the interface. The still is evacuated to saturation pressure at cabin temperature, approximately 3.45kNm^{-2} abs. (0.5 psia), and the tankage is pressurized to nearly 137.9 kNm^{-2} abs. (20 psia). Thus the two streams which leave the still and enter the tankage (recycle and distillate) must be elevated in pressure, and the feed stream which flows the opposite way must be metered to prevent flooding the boiler.

The flow rate required in each of the streams is proportional to the distillate production rate. Minimum feed flow rate is five times distillate production rate to maintain adequate solubility in the boiler exit stream (recycle stream). Maximum feed flow rate is seven times production rate to prevent an excessively thick waste liquid film on the boiler heat transfer surface. For the RLSE design, the pump was sized to feed liquor at six times production rate. Minimum recycle pump capacity should be greater than the maximum feed rate to insure that waste water never accumulates within the boiler; thus the recycle pump was designed with 25% greater flow capacity than the feed pump. Minimum condensate pump capacity is, of course, the maximum distillate production rate. All of the pumps should be driven by the same motor and be on the same shaft to keep the flow rates in proportion. But more importantly, should any pump fail it is either necessary or advisable to stop all other pumps.

The liquids pump design requirements are listed below; they are based upon a nominal water production rate of 1589μm^3/hr (3.5 lb/hr).

Stream	Input From	Output To	Head Rise (psid)	kNm^{-2}	Flow Rate (lb/hr)	$\mu m^3/min$
Feed Liquor	Recycle Tank	Boiler	(-19.5)	-134	(3.5x6=21) (9.6 in^3/min)	159
Recycle Liquor	Boiler	Recycle Tank	(+19.5)	+134	(21x1.25=26.25) (12.1 in^3/min)	>199
Distillate	Condenser	Use Tank	(+19.5)	+ 134	(3.5) (1.6 in^3/min)	> 27

Peristaltic tubing pumps are the best of all known types to meet these requirements - especially considering that the recycle and condensate streams originate in chambers at saturation pressure. Virtually no inlet pressure losses can be tolerated and virtually no heat can be generated during compression. The selection of peristaltic tubing pumps was made after exhaustive studies, both analytically and empirically, by Chemtric and others. The significant penalty associated with peristaltic pumps is limited tubing life.

Maximizing tubing life requires that:

1. No more than one tubing compression be imposed by each pump revolution. Thus a long-life peristaltic pump must be designed with a single roller, rather than the two or three rollers popular in conventional pumps.
2. The tubing material be resistant to fatigue as well as resistant to chemical attack. Norton Plastics' formulation No. R-3603 is the best known material which meets these requirements. It was formulated specifically for peristaltic pump applications.
3. The tubing be locked in place in the housing to prevent both axial and circumferential movement. Axial movement will permit abrasion between adjacent tubes or with the pump housing. Circumferential movement will cause tensile stresses which when combined with the bending stresses applied by the roller will generate a high shear stress at the convolution formed under the roller. Excessive circumferential movement will cause partial or complete flattening of the tubing with a reduction or complete stoppage of flow.

5. The roller apply minimum stresses to the tubing. During the program it was postulated that circumferential stresses imposed by a rotating roller are both unnecessary to fundamental pump action, and are avoidable. That is: it is possible to apply only radial stresses to the tubing.

As reported earlier in section 3.1, a special case of hypocycloidal motion was tested during peristaltic pump development. Although the desired kinematics were achieved, the tubing life was severely curtailed and the original concept of a large roller reinstated.

The general configuration is that of a conventional omega-tube peristaltic pump, but with three tubes and a single roller. See Figure 3-1. The roller is carried in bearings on an eccentric member which is very much larger than its eccentricity. The eccentric member is rotated about its concentric inside diameter by a gearmotor. As shown on the drawing the peristaltic tubes are retained to the housing by circular clamp rings assembled axially with the tubes. A flange under the protective cover retains the rings and applies the axial clamping force.

Norton Plastics Company's formulation No. R-3603 was extruded in a para-tube configuration to generate the clamping cleat on the tubes. The clamping cleat configuration serves to prolong life by reducing the shear stresses which eventually cause fracture, and by reducing the strain (circumferential movement) which eventually may cause flattening.

Attachment of the tube ends is made with barbed connectors and permanent clamps over the barbs. The connectors are sealed to the housing by O-rings and held in place by screws. Integrated into the housing are component-side interface valves. Those valves and the adjacent system-side interface valves are to be rotated manually to the shutoff position to replace the pump. That approach is identical in principle to the SSP maintenance valve approach; design improvements have been made to reduce weight, cost and bulk and to eliminate replacing the plug - which is by far the most reliable part of the SSP valves. The stainless steel plugs are purchased from Circle Seal Corp. and are presently used in high quality manually-operated valves.

As stated above the feed pump operates with a negative head rise of approximately 134 kNm^{-2} (19.5 psid). Peristaltic pumps so operated have an effective volumetric efficiency of approximately 110 percent. That phenomenon is caused by elastic expansion of the tubing at the pressurized inlet. Conversely, with a positive head rise as is present in the recycle and condensate streams the volumetric efficiency is near 100 percent. To accommodate the volumetric efficiency difference and to insure that recycle pump capacity will always be greater than feed flow rate the feed pump tube diameter is smaller than that applied in the recycle pump. The condensate pump could have been built with either size tubing - both provide adequate capacity to accommodate condensate flow rate. No penalty is incurred by selecting the larger size because the greater displacement simply draws water vapor from the condenser. That vapor is condensed to liquid as it is pressurized within the pump. The latent heat extracted from the condenser by extracting vapor is insignificant.

Approximately 18 percent of a tube's volume is occupied by the roller's "footprint" and is therefore unavailable to contain liquid. The displacement per roller revolution is .82 x vol. eff. of a tube's internal volume. The effective length of the tubes shown by the assembly drawing is approximately 94 percent of the circumference at the tubing pitch circle. Displacement per revolution is:

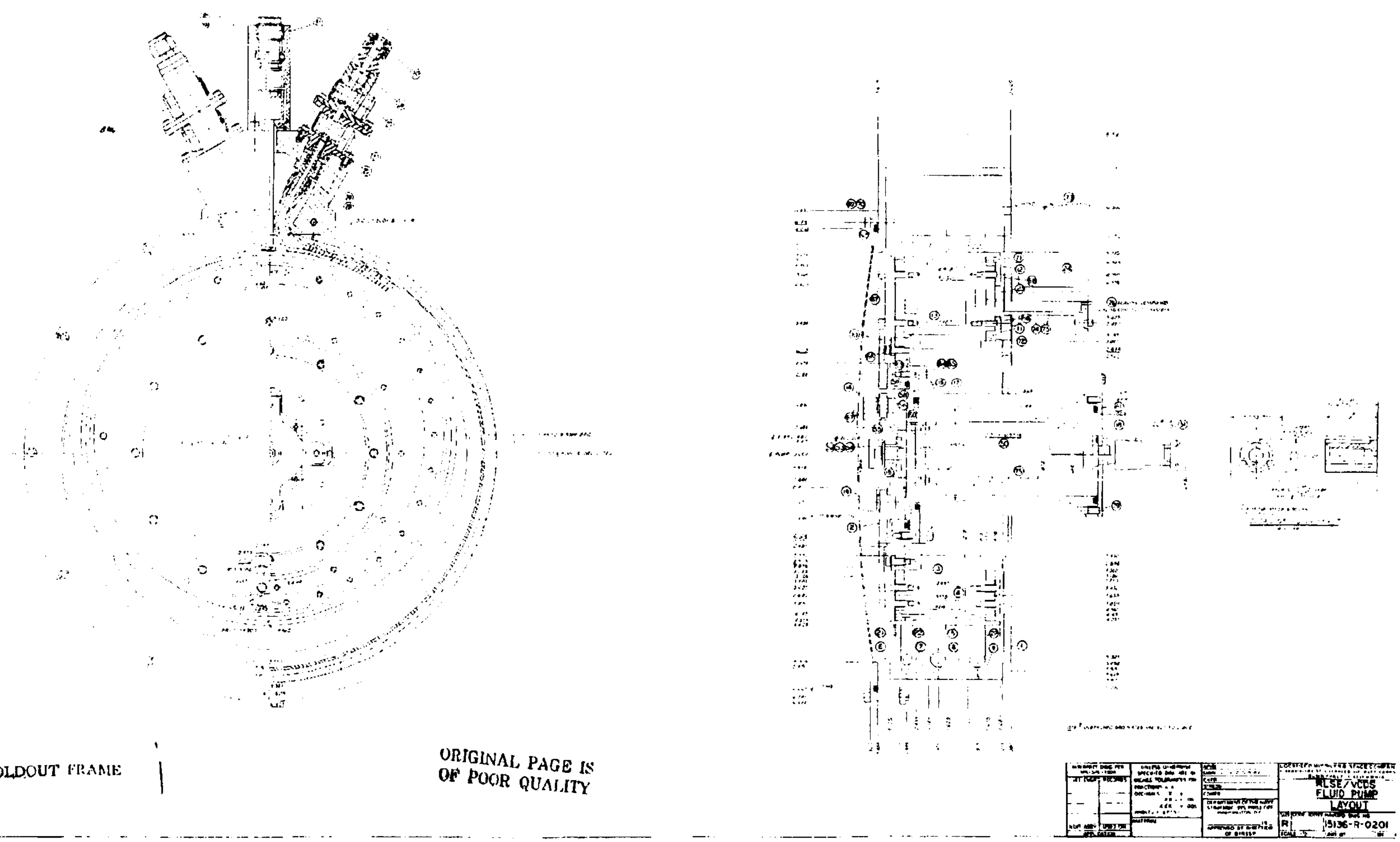
$$\frac{(\text{Tube I.D.})^2 \pi}{4} \times \text{Tube Pitch Dia} \times \pi \times .94 \times .82 \times \text{Vol. Eff.}$$

For the feed pump (.156 Tube I.D.) the displacement rate is

$$\frac{(0.156)^2}{4} \pi^2 \times 9.75 \times 0.94 \times 0.82 \times 1.10 = 8.12 \mu m^3 \ (0.496 \ in^3)$$

For the condensate and recycle pumps (.190 Tube I.D.) the displacement rate is

$$\frac{(0.190)^2}{4} \times \pi^2 \times 9.75 \times 0.94 \times 0.82 \times 1.0 = 10.96 \mu m^3 \ (0.669 \ in^3)$$



FOLDOUT FRAME

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Figure 3-1 VCD Fluids Pump Assembl

FOLDOUT 2

The speed required is

$$\frac{\text{Design Flow Rate}}{\text{Displacement Rate}} = \text{RPM}$$

for the feed pump:

$$\frac{9.6 \text{ in}^3/\text{min}}{0.496 \text{ in}^3/\text{rev}} = 19.3 \text{ RPM}$$

for the recycle pump:

$$\frac{12.1 \text{ in}^3/\text{min}}{0.669 \text{ in}^3/\text{rev}} = 18.0 \text{ RPM}$$

and for the condensate pump:

$$\frac{1.6 \text{ in}^3/\text{min}}{0.669 \text{ in}^3/\text{rev}} = 2.4 \text{ RPM}$$

Thus the feed pump requires the highest speed, 19.3 RPM, and establishes the required pump speed. The additional speed imposed upon the recycle and condensate pumps represent excess capacity and vapor extraction from the distillation process. Vapor extracted by the condensate pump is condensed and delivered as condensate. Vapor extracted by the recycle pump is condensed and becomes a diluent in the waste liquor. Maximum vapor extraction rate by the recycle pump occurs when recycle flow is insignificant. Latent heat loss also is insignificant, especially when it is realized that the condenser must reject heat to ambient.

A 90 day endurance test was commenced at LMSC shortly after receipt of the liquids pump. A test rig simulating the head rises and flow characteristics of VCD was constructed. Power averaged 23 W, slowly increasing in a week to 32 W. Inspection of the pump disclosed dry tubes, empty lubricators, and moisture in the pump casing. The tubes were hand lubricated, and the test resumed. Within a day power increased above 42 W and the gear motor (Model 83A 1119-639.9 TRW Globe, Dayton, Ohio 45404) was very noisy. A second inspection found a large quantity of water in the pump casing. The moisture resulted from a defective water supply valve and a common vacuum line to both the pump casing, and the simulated still. Even before the gear motor became wet, there were indications that it was not performing as expected. After discussions with the motor manufacturer, it was decided to upgrade its capability. Since only 165 hours of a planned 2160 hour test had elapsed at this time, it was also decided to refurbish the entire pump and restart the endurance test. New tubes, pins, bearings, tube lubricator, lubricant, and the new gear motor were installed. The new gear motor (Model 83A1119-639.9-AV229) had an uprated gearbox which was designed to supply the required torque continuously.

Before installing the gearmotor, a spot check of its delivered torque and wattage was made. A check was also made of the torque requirements of the pump. Although the motor was not being overloaded, the gearbox appeared to be operating at or near its limit. While replacing the new parts, a keeper ring was fabricated and installed to maintain pressure on the tube and clamp ring stack whenever the cover was removed.

Aware that the limits of the 83A119-639.9-AV229 gear motor were being approached, a considerably stronger gear motor was ordered (83A850) and new parts were designed and fabricated to adapt it to the pump.

The test rig was reconfigured to eliminate the possibility of flooding the pump casing, and the test restarted. Power was 28.5 W.

Flow rates were $145 \mu m^3$ (145 ml)/min feed, $186 \mu m^3$ (186 ml)/min recycle, and $154 \mu m^3$ (154 ml)/min condensate. At 96 hours, power had risen to 40 W and the gear motor was noisy. Inspection of the pump disclosed that about one inch of the feed tube had migrated towards the outlet, the required drive torque of the pump had not changed, but the motor gearbox was failing. The feed tube was replaced, and the test stopped until the 83A850 gear motor arrived.

The 83A850 gear motor was installed and power measured at 29 W. Power and flow rates remained satisfactory until a feed tube failed at 367 hour. For the second time, the feed tube had migrated circumferentially this time looping around the new lubricator tube and chafing through. The migration of the feed tube towards the pump outlet seemed to conflict with the hypocycloidal experience related in the purge pump development (3.1). It was concluded that in spite of the retrograde kinematics involved, roller friction and insufficient clamping of the paratube were permitting the tube to stretch. The tube was replaced and an additional ring added to increase the squeeze on the entire stack. The lubricator tubes were modified to prevent a recurrance of this failure. The test resumed.

At 553 hoursthe pump once more failed. This time the feed tube had migrated to cause what appeared to be a jamming of the roller and a failed gearbox due to overload. However, the motor manufacturer felt that the gearbox had failed due to loss of lubricant in the primary stages of reduction. Nevertheless, the migration of the feed tubing was not responding to increased squeeze. Therefore, the following steps were taken to lock the tube in place:

1) The paratube was stuffed with a 3.1 mm (0.125 in) dia. soft aluminum wire.
2) A dowel pin was placed directly in the path of this wire at the pump outlet and locked to the pump casing.
3) The feed tube clamp rings were stippled to increase the grip on the paratube.
4) The additional squeeze ring was discarded.

The gear motor was refurbished and a different, less viscous lubricant installed in the gearbox. The test resumed until 1054 hourswhen the condensate tube failed. This failure was attributed to the procedure of shutting off flow overnight. The accrued time with no flow apparently exceeded the tube material capabilities. The tube failed by cracking outside to inside not at the 180° bends, but at the point nearest the roller. The tube was renewed and the test procedure changed. At 1097 hours the 83A850 gear motor again failed. This failure was the same as before,i.e. lubricant loss in the primary stages of reduction. The manufacturer at this point was forced to admit that the minimum life rating of 1000 hours was not going to be met. Accordingly, he recommends that the gear box be repacked every 250 hours. The gearbox was refurbished and filled with Aeroshell 7 lubricant/class III fill. A gearbox identity was created (1A3688) for spares ordering purposes. The endurance test was stopped and the liquids pump operated only during VCD systems tests. Since return to operation, an additional 140 hours has been placed on the motor for a total of 1237 hours. The installed liquids pump is shown in Figure 3-2 . The inlet connections are to the right and outlets to the left. The feed pump is at the top, recycle pump in the middle, and the condensate tube on the bottom. The lubrication ports are shown centered between inlet and outlet. The case vacuum connection is directly below the lubricators and in front of the rotation sensing reed switch. The gear motor is contained in the fluted cylinder below the pump section.

3.3 Electrical Controller, and Display Panel Development

The SSP/VCD Controller had several problems which required evaluation and correction:

1) Lack of the ability of the controller to automatically return the diverter valve to the "non divert" position after the product water has returned to a satisfactory condition; the method of return to "non divert" was manual.
2) Failure of timing circuits to reset.
3) Solid state relay failures.

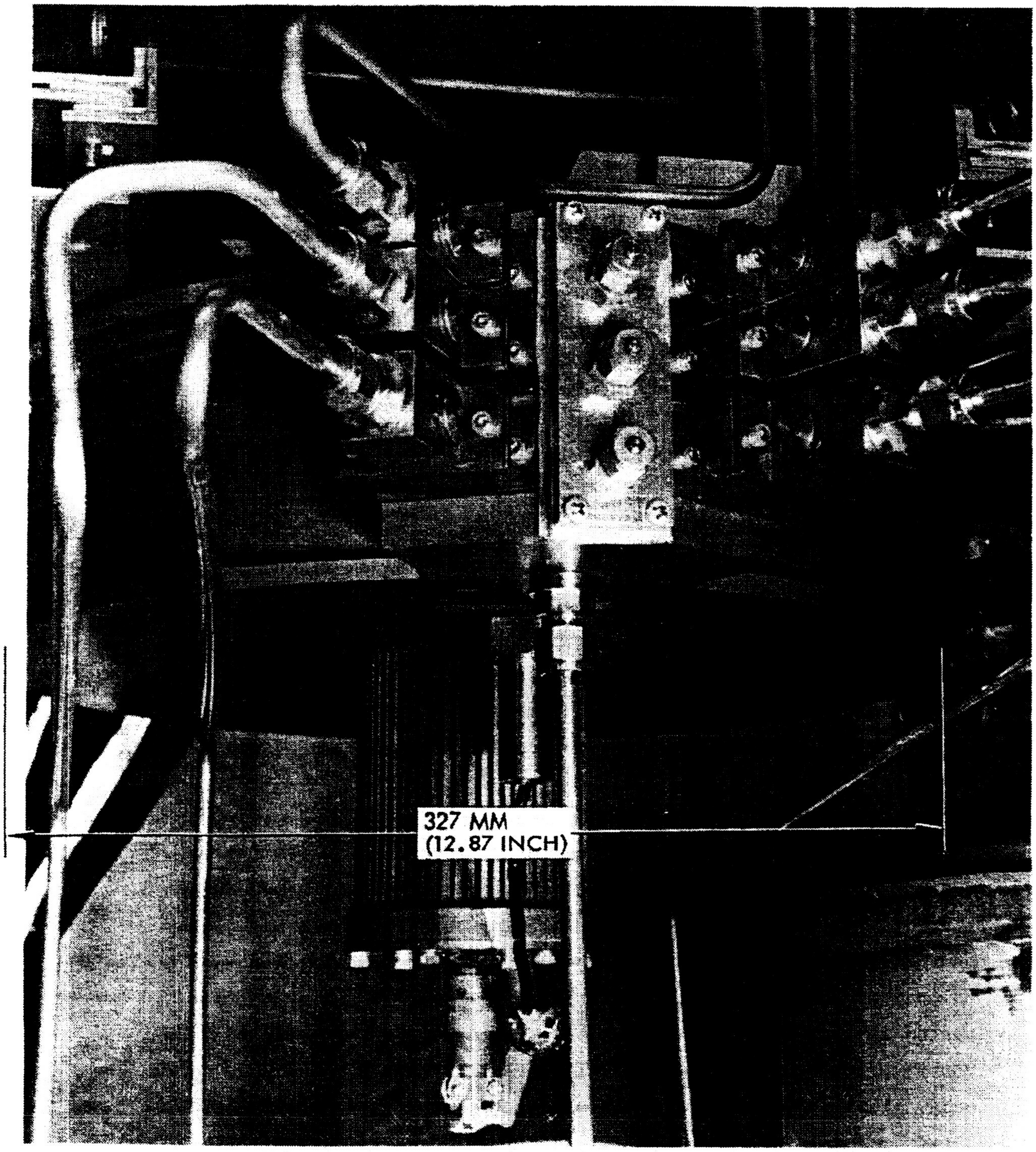


Figure 3-2 VCD Liquids Pump

4) Controller logic which permitted the still motor to be deactivated when certain "emergency shutdown" failure modes occurred.

5) Insufficient or inadequate parametric display for the monitoring of the VCD when running.

A review of the original controller design and capabilities was made. Besides power input, the original Controller had 8 sense inputs, two of which were valve drive state feedbacks. The Controller generated control signals for five loads: the compressor drive motor, two pumps, and two valves and provided two different time delays.

With an appreciation of the VCD functions, a review of the schematic of the SSP controller and the controller component specification was made to define operational modes. This review reduced the VCD functions, sensor sources of information, and controller loads to a form from which the controller's basic logic equations for each operational mode could be written.

Four operational modes were determined. They were: STOP (Standby), STARTUP, RUN (Normal and high water conductivity submodes) and DRYDOWN.

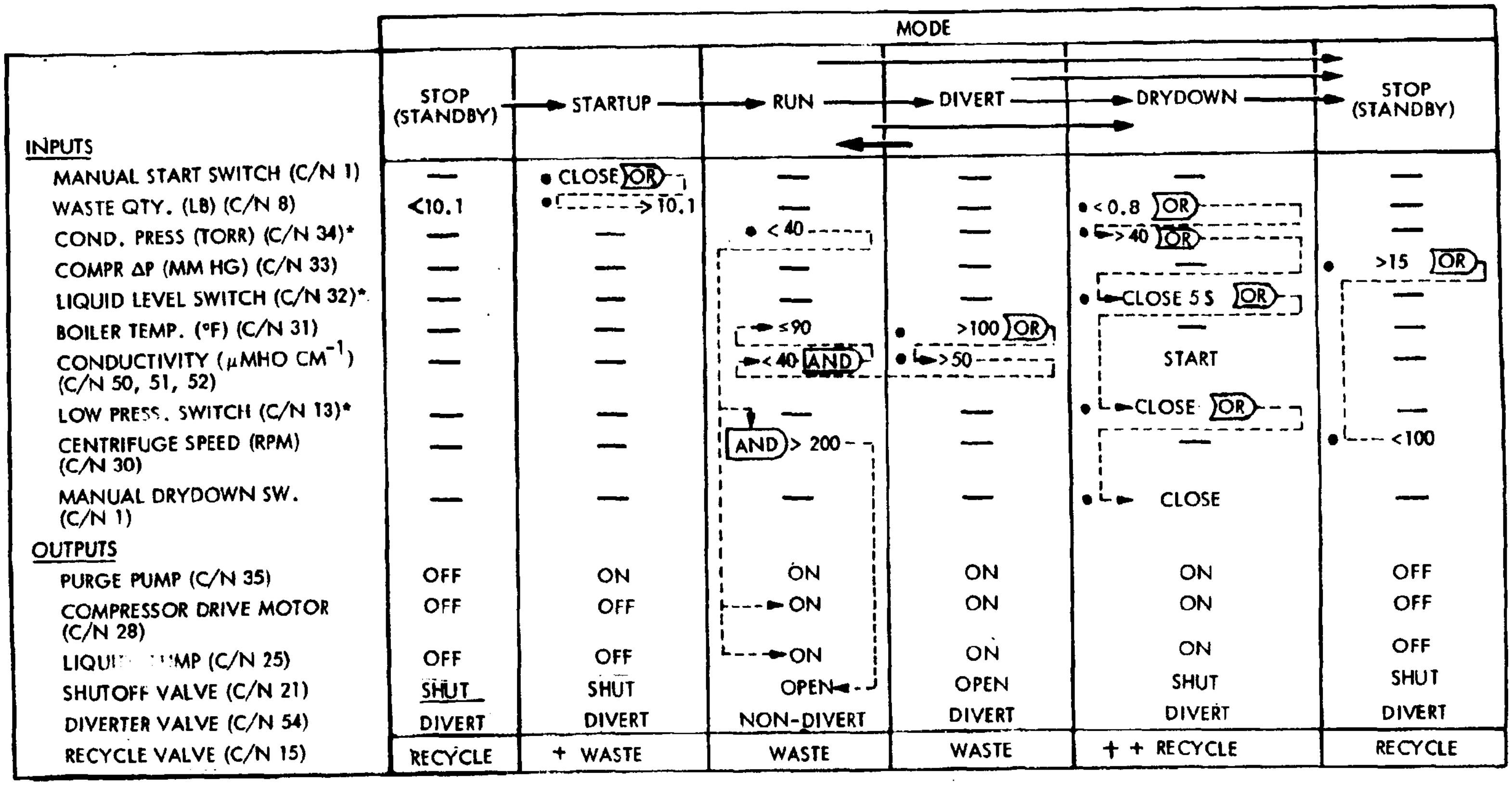
The SSP concept of fault detection and corrective action was based on an overall system computer program which monitors each subsystem. If an abnormality were to occur, a centralized display or input/output station would alert the operator to take action. Accordingly, the VCD had no display panel, and development efforts required extensive "patching" to monitor its operation. Not wishing to abandon this capability of remote system level monitoring and fault detection, it was decided to retain all control functions in the controller and add a panel for display purposes only. This display could be used for development purposes and replaced later by the software routine if desired. The display panel may be entirely disconnected from VCD without affecting its operation.

Controller redesign was deferred until the VCD mechanical schematic, failure modes and effects analysis, and component developments became more mature.

For example, skepticism existed as to the reliability of the condensate conductivity sensor. It was decided to triplicate the sensors and establish a voting logic wherein any two sensors in agreement as to condensate conductivity would prevail. Another unexpected development was the incorporation of an alternative recycle logic path into the controller. This path required the addition of a motorized valve and the necessary control circuitry.

The resultant VCD Controller Logic Diagram is shown in Figure 3-3 . In this diagram, the inputs and outputs are arrayed versus the various operational modes. Five operational modes are established: STOP (Standby), STARTUP, RUN, DIVERT, and DRYDOWN. STOP (Standby) is repeated at the right end of the figure to assist the reader in understanding the logic flow, but does not differ from the STOP (Standby) mode shown to the left. The controller logic is sequence sensitive, and generally progresses from left to right. The exception: it is normal to return from DIVERT to RUN. It is also normal to bypass modes. From RUN, it is normal to go directly to DRYDOWN or STOP. From DIVERT, it is normal to go directly to STOP.

When powering up the VCD, the logic is automatically reset to STOP. A reset switch on the controller performs the same function. The shutoff, diverter, and recycle valves are driven to the position indicated. In this mode the waste quantity is less than 4.58 kg (10.1 lb). Upon attainment of more than 3.63 kg (8 lb) of waste in the waste tank, the recycle valve is driven to the waste position where it remains until the waste quantity drops below this value. As the waste quantity continues to increase and becomes more than 4.58 kg (10.1 lb), the controller enters STARTUP. Mode initiators and logic gates are shown on the figure. In STARTUP, the purge pump is turned on causing condenser pressure to decrease to less than 5.33 kNm^{-2} abs. (40 torr). This initiates the RUN



● MODE INITIATOR
*IF DRYDOWN INITIATED BY ANY OF THESE PARAMETERS THEN SUBSEQUENT STARTUP REQUIRES MANUAL OVERRIDE
\+ GOES TO WASTE POSITION WHEN WASTE QTY > 8 LB
\+ + GOES TO RECYCLE POSITION & LATCHES WHEN WASTE QTY DECLINES FROM >8 LB TO < 8 LB REGARDLESS IF SUBSEQUENT WASTE QTY > 8 LB

Figure 3-3 VCD Controller Logic Diagram

mode but does not fully establish it. Certain other conditions must be met. The compressor drive and liquids pump motors are energized. Energizing the compressor drive motor causes centrifuge rotation and upon achievement of 200 RPM, the shutoff valve motor is energized in the open direction. When the shutoff valve opens, and the valve position indicator so indicates, RUN is established, and the divert valve motor is commanded to the non-divert position. In case of mechanical hangup a timer removes the command to all valve motors after 30 seconds to prevent motor burnout.

In the event boiler temperature exceeds 37.8°C (100°F) or condensate conductivity exceeds 50 μmho cm^{-1} the controller establishes DIVERT and the diverter valve is placed in the divert position. When boiler temperature drops below 32.2°C (90°F) and condensate conductivity drops below 40 μmho cm^{-1}, RUN is reestablished and the diverter valve is returned to the non-divert position.

DRYDOWN is initiated by any of five different parameters. The normal cause of DRYDOWN is low waste quantity. As mentioned before, the recycle valve is placed in recycle position when waste quantity declines below 3.63 kg (8 lb). The valve control logic remains latched in this state until STOP, regardless if a sudden inflow of waste causes the quantity to rise above 3.63 kg (8 lb). When DRYDOWN is entered, the shutoff valve is shut and the diverter valve is placed in divert position. Other causes of DRYDOWN are the consequence of abnormalities: condenser pressure exceeding 5.33 kNm^{-2} abs. (40 torr), or a sustained liquid level switch closure of 5 seconds, or a momentary low pressure switch closure, or manual operation of the drydown switch.

With the valves placed in the positions indicated, the boiler eventually goes dry and the compressor delta pressure exceeds 2 kNm^{-2} (15 mmHg). When this event is achieved, STOP occurs, and purge pump, liquids pump, and compressor drive motors are turned off. As an emergency provision, centrifuge speed of less than 100 RPM also causes STOP. The 100 RPM state is enabled by first achieving a 200 RPM rate. From STOP, the VCD is once again free to enter the STARTUP, RUN cycle.

The VCD Controller was originally constructed by Hamilton Standard Div. of United Technologies Corporation utilizing CMOS logic and bi-polar operational amplifiers, constructed on wire wrap circuit boards. Solid state relays were used to switch powered elements. Power input is 400 Hz, 3 phase, 208 V (line to line). Two power supplies provided DC power to logic circuits, and excitation of transducers. The addition of one operational mode, additional conductivity sensors and associated voting logic, as well as other sensors required the doubling of wire wrap boards. Deciding to expand the Controller rather than start anew, the controller box was enlarged and the new circuitry added. The Controller is shown in Figure 3-4.

The display panel shown in Figure 3-5 was designed using established human factors engineering techniques and provides a continuous, readable, portrayal of VCD operational status. The panel represents a simplified version of the subsystem schematic. Major components with indicator lamps, needle movements, and counters, are depicted in dark on a light background. Basic fluid pathways with directional arrows indicate flow routing from component to component. At the top of the panel is a display of operating mode and time. If, in the absence of an observer, DIVERT or DRYDOWN is entered, a lamp is caused to light identifying the cause. A latching circuit holds the lamp lighted even after leaving DRYDOWN or DIVERT. Lamp latches are released and reset when next entering RUN. While in DIVERT, the cumulative time and number of DIVERT occasions are totaled until reset. The DIVERT cause lamp latch circuits are reset at each entry to DIVERT so that the lamp lighted is indicative of the latest cause.

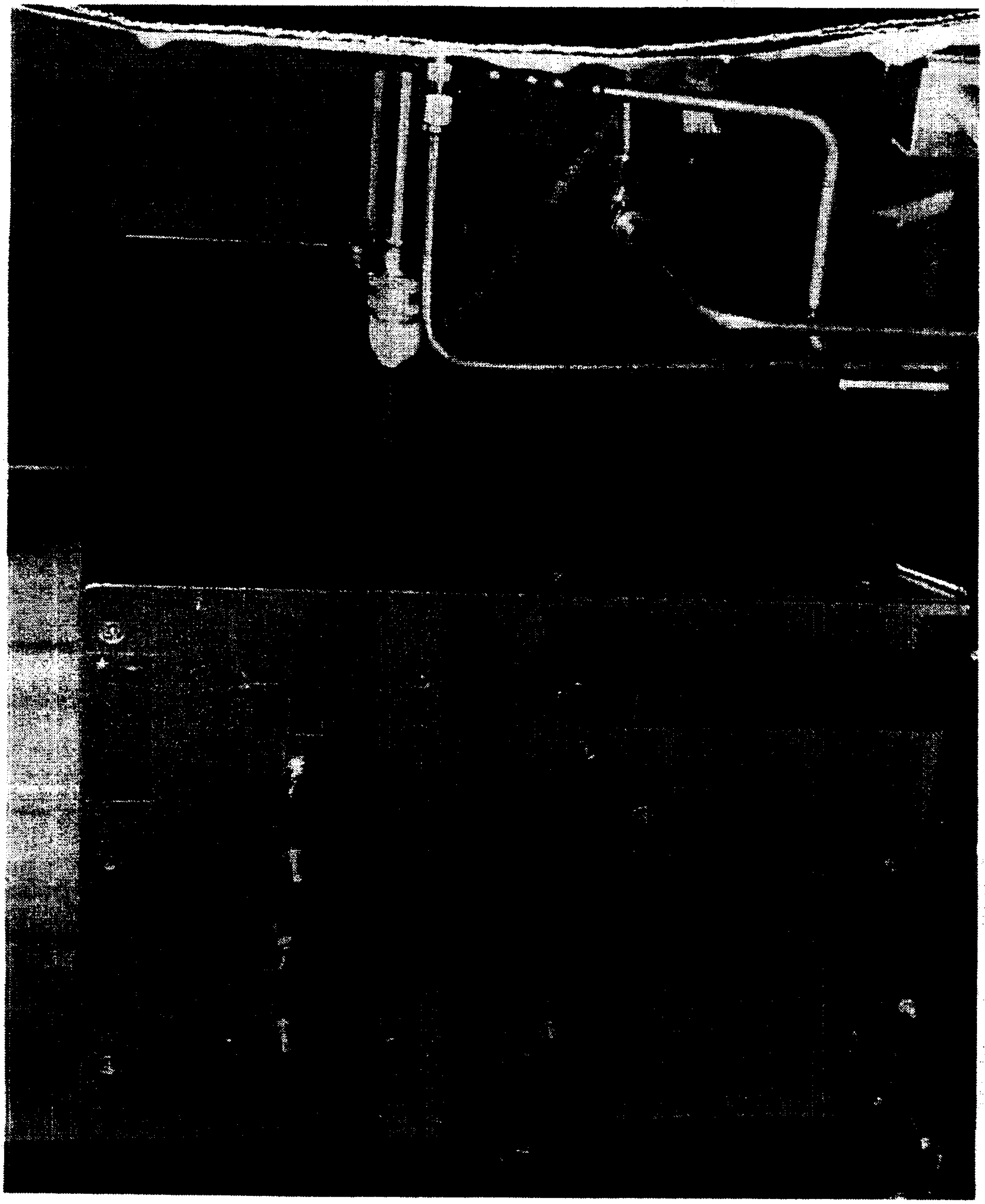


Figure 3-4 VCD Controller

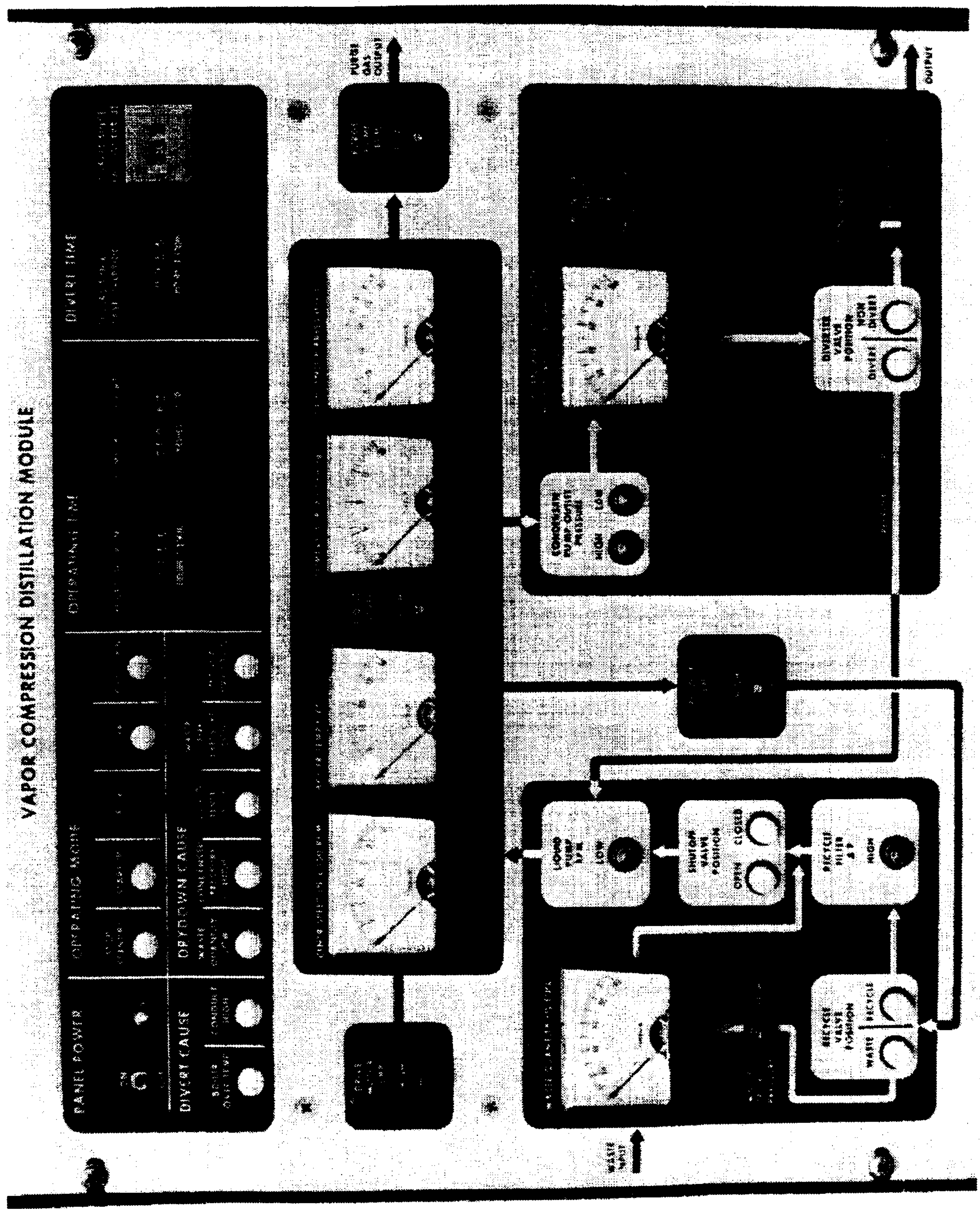


Figure 3-5 VCD Display Panel

A thermal switch in the compressor drive motor controls the high drive motor temperature lamp. The high liquid level lamp is designed to flicker as random splashes impact the sensor. After five seconds of continuous activation of the liquid level sensor, the controller enters DRYDOWN as discussed earlier, and the display DRYDOWN CAUSE "liquid level high" lamp latches on. The low purge pump RPM lamp is not activated because of a late selection of purge pump type.

The liquid pump low RPM lamp is controlled by a timing circuit with a time constant slightly larger than the liquid pump roller period. Each revolution of the roller resets this timer. If the roller were to stop, or significantly slow, the lamp will flash. The waste tank pressure low lamp is controlled by a pressure switch, and protects against creating a vacuum in the waste input line. The recycle high delta pressure lamp indicates a blocked filter. The recycle high pH lamp is set to light at pH of 4 or greater. The condensate pump outlet pressure is monitored by two pressure switches. One is set for high pressure and indicates a pump blockage. The other is set for low pressure and indicates tube failure. Condensate conductivity is meter displayed and one of the three sensors may be monitored by operating a three position selector switch. Condensate which is delivered by VCD to the next subsystem is recorded on an electro/mechanical counter in discrete increments concurrent with periodic operation of the condensate booster pump.

The display panel is 482.6 mm (19 in.) wide for standard rack mounting. A 115V, 1 phase 60 Hz power supply provides the necessary circuit and lamp power. Six circuit cards in a slide-in card cage contain all the display circuitry. A large multi-pin connector provides access to VCD for recorder hookup.

3.4 Chemical Pretreat Formulation and Metering Unit Development

Early efforts in the development of water recovery systems clearly indicated the value of pretreatment of human waste prior to distillation. These early efforts were directed toward control of microbial growth in urine which can serve as nutrient growth media for a large variety of microorganisms. Other ingredients to control foam and to reduce co-distillation of volatile substances such as ammonia were added in later developments.

In 1966 under contract AF 33(165)-2124, pretreatment chemical containing iodophor disinfectant, silicone antifoam, sulfuric acid and water was used in a successful 14 day test of a VCD unit. The only VCD unit to have operated for any period of time has used a blend of the above ingredients.

The first use in 1966 of the pretreatment chemical discussed above, revealed that the commercial iodophor (Wescodyne) used contained isopropyl alcohol. The alcohol co-distilled with water and produced objectionable product water. This problem was eliminated by exposing the iodophor to distillation conditions prior to use in the VCD unit, thereby stripping out the volatile contaminant. Some iodine losses occurred. The iodine concentration was restored to the original value by mixing in finely divided iodine crystals.

Under NAS 9-9191, the pretreatment chemical was improved by the use of Biopal VRO-20 iodophor (20 to 22% available iodine). A 50% reduction in weight penalty was realized without any detectable loss of performance.

The amount of pretreatment chemical per unit volume of urine was determined under contract NAS 9-9191. Systems considerations dictated use of a specific quantity of pretreatment chemical with each micturation. The nominal micturation volume is $260 \mu m^3$ (260 ml). The amount of pretreatment chemical used per micturation was 2.25 grams. The following lists the ingredient quantities and concentrations based on the anhydrous state:

1.	Biopal VRO-20	0.66 gms	29.3%
2.	Sulfuric Acid	0.34	15.1%
3.	Antifoam	0.13	5.8%
4.	Water	1.12	49.8%
		2.25	

The pretreatment chemical has been used successfully in more than 120 days of system tests. No system problems or malfunctions have ever been attributed to the pretreatment chemical in over ten years of testing. Recent studies under NAS 9-12843 have identified Biopal VRO-20 as a source of a volatile contaminant; specifically dioxane. Based on the experience cited previously, such volatiles should be stripped from the iodophor by exposure to vacuum distillation conditions prior to blending of the pretreatment chemical. An area notpreviously explored, was the long term stability of the pretreatment chemical. It had not been stored for periods longer than 60 days.

The areas studied during the development effort were 1) mixture stability, 2) absence of volatiles, 3) pretreatment formulation for hyperfiltrated wash water, and 4) development of a pretreatment metering unit integrated with a GFE urinal.

<u>Mixture Stability</u> - The ingredients must remain uniformly dispersed if accurate dosage and consequently, nominal performance is to be realized. The formulation is complex and separation into discrete layers can occur as is typical of such mixtures. Such separations are likely to occur when exposed to changes in environmental conditions. Temperature extremes are usually most effective in "breaking" emulsions.

Testing was conducted to identify potential storage problems. The pretreatment chemical was subjected to normal ambient storage as well as elevated temperatures. The stability was evaluated by specific chemical analyses to quantify any changes. Details will be discussed in a subsequent section.

Volatiles Tests - The iodophor consists of iodine and a detergent like organic compound identified as nonylphenylpolyethoxy ethanol. The terminal group can be diagramed as:

$$R\text{-}O\text{-}CH_2\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH_2OH$$

Dioxane can be synthesized by dehydration of alcohols. It is most unlikely that dioxane (a cyclic ether) can be produced within the pretreatment chemical because of the high water content. However, the ingredients are present and the behavior of the terminal ether-alcohol groups at the end of a long chain is unpredictable. Other routes of acid attack similarly cannot be ruled out. Elevated temperature would accelerate such a phenomenon.

The pretreatment chemical volatiles content were tested as part of the storage studies by comparing current formulation techniques with and without prestripping. Samples were then added to urine, processed in glassware and the product water analyzed for organics.

The first step in the dioxane study was to review the report prepared under Contract NAS 9-12843. In this report, vacuum distillation of pretreated urine in glassware was performed at 4.8 kNm^{-2} abs. (36 torr). The first fraction (20%) was analyzed by direct injection of liquid distillate in a gas chromatograph equipped with a flame ionization detector. This technique was unsatisfactory owing to the low concentrations of volatiles in the distillate. Therefore it was necessary to employ a headspace analysis technique. Results of this procedure indicated the presence of dioxane in the distillate and the Biopal VRO-20. A subsequent headspace analysis using a gas chromatograph-mass spectrometer complex was unrewarding due to bleed interference and low concentration of volatiles. By concentrating the volatiles from 100 to 1000 times more than the headspace analysis alone, positive identification of dioxane was made. The same concentrate was analyzed by a gas chromatograph equipped with a flame ionization detector. The results of these analyses unequivocally identified dioxane in the first fraction of distillate at an estimated concentration of 340 ppm.

LMSC questions the accuracy of this finding since concentrations of this level should have been detectable in the direct liquid injection technique first attempted. The gas chromatograph at LMSC equipped with a flame ionization detector is capable of measuring dioxane concentrations as low as 1 ppm. Conducting glassware fractional vacuum distillations of pretreated urine at LMSC resulted in dioxane concentrations of 4-8 ppm concurrent with a total organic carbon (TOC) concentrations of 14. This harmonizes closely with Chemtric reported data of chemical oxygen demand (COD) of 20-100 of VCD distillate. When LMSC examined a sample of actual VCD condensate, it was found to have less than 1 ppm dioxane.

A sample of pretreat mixture was found to have very little dioxane, however vacuum distillation of the pretreat mixture itself produced 1350 ppm in the condensate. Distillation of "stripped" pretreat mixture and urine yielded 10.9 ppm in the distillate. It is apparent that "stripping" the pretreatment mixture does not eliminate dioxane production. Possible explanations for the variance between glassware and VCD dioxane production are 1) dioxane gets purged out of VCD or 2) glassware doesn't fully represent VCD conditions.

A search to determine official allowable dioxane toxicity limits to humans in water was unsuccessful, however 50 ppm in air to humans and 100 ppm in water to laboratory rats is acceptable. In another test, activated charcoal was found to reduce 4.7 ppm dioxane in water to less than 1 ppm by adsorption.

When first checking for available iodine (I_2) in the pretreated urine immediately after mixing, none was found. Apparently, the urea and other organics consumed all the I_2 that was originally introduced. Previous investigators utilized aged refrigerated urine together with flush water dosed to 1 ppm with silver ions. Perhaps these measures allowed more I_2 to survive. At LMSC bacterial activity was noted after only 5 days. Accordingly, the iodophor content of the pretreat mixture was increased. The new formulation is shown in Table 3-2.

Table 3-2

Pretreatment Formulation

Ingredient	Amount (g)
Biopal VRP-20	1.23
Sulfuric Acid	0.34
Antifoam	0.13
Water	1.30
	3.00

The water constituent was increased from 1.17 g to 1.30 g to assist in mixture viscosity control. With this formulation established, dioxane levels were checked throughout the pretreat mixture stability test program for evidence of pathological change. Results are tabulated in Table 3-3 and shown graphically in Figure 3- 6 .

Although the concentrations are higher than desired, it is concluded that actual VCD condensate will not only be less, but will be well below toxicity limits, and that any trace amounts which may occur could be effectively removed by carbon adsorption.

Pretreat mixture stability tests were performed by storing one batch at room temperature and another batch at 37.8°C (100°F). At the end of each month, two samples of urine and flush water were pretreated using one each of the pretreat mixtures. The formulation was 3 g pretreat mixture, 260μm^3 (260 ml) fresh urine, and 150μm^3 (150 ml) distilled water. These pretreated samples were allowed to stand at room temperature for 7 days. After 7 days of aging, the samples were checked for I_2 and then vacuum distilled in glassware apparatus shown in Figure 3- 7. The first 10% of condensate was examined for TOC and dioxane. The zero month decay of I_2 is presented in Figure 3-8 and shows 7 days aging to be the practical limit for pretreated urine.

Sample Month	Date* Mixed	Date Distilled	21.1°C (70°F) Sample Dioxane	21.1°C (70°F) Sample TOC	37.8°C (100°F) Sample Dioxane	37.8°C (100°F) Sample TOC	Fresh Sample Dioxane	Fresh Sample TOC
0	1/7/77	1/14/77	13	18	-	-		
1	2/7/77	2/14/77	83	24	122	50		
		3/9/77	(36)		(21)			
2	3/7/77	3/14/77	35	31	27	24		
3	4/7/77	4/14/77	8	8	21	11	29	16
4	5/9/77	5/16/77	21	46	20	16		
5	6/6/77	6/13/77	21	16	23	14		
6	7/7/77	7/15/77	20	23	21	16		

*Pretreat Chemical + Urine + Flush Water (1.23 g Biopal/Micturation)

Table 3-3

Urine Pretreat Stability Tests

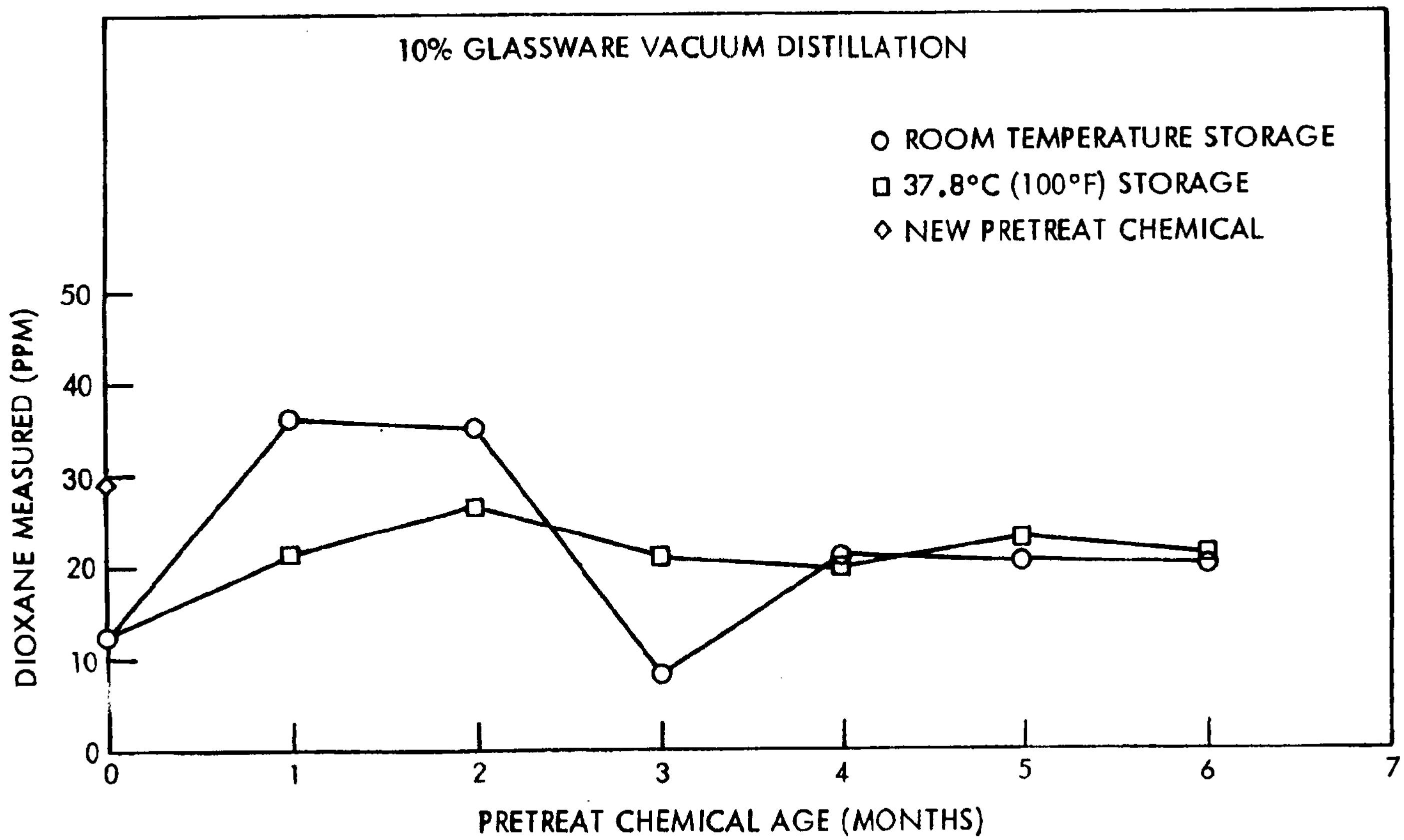


Figure 3-6 Pretreat Chemical Stability Test

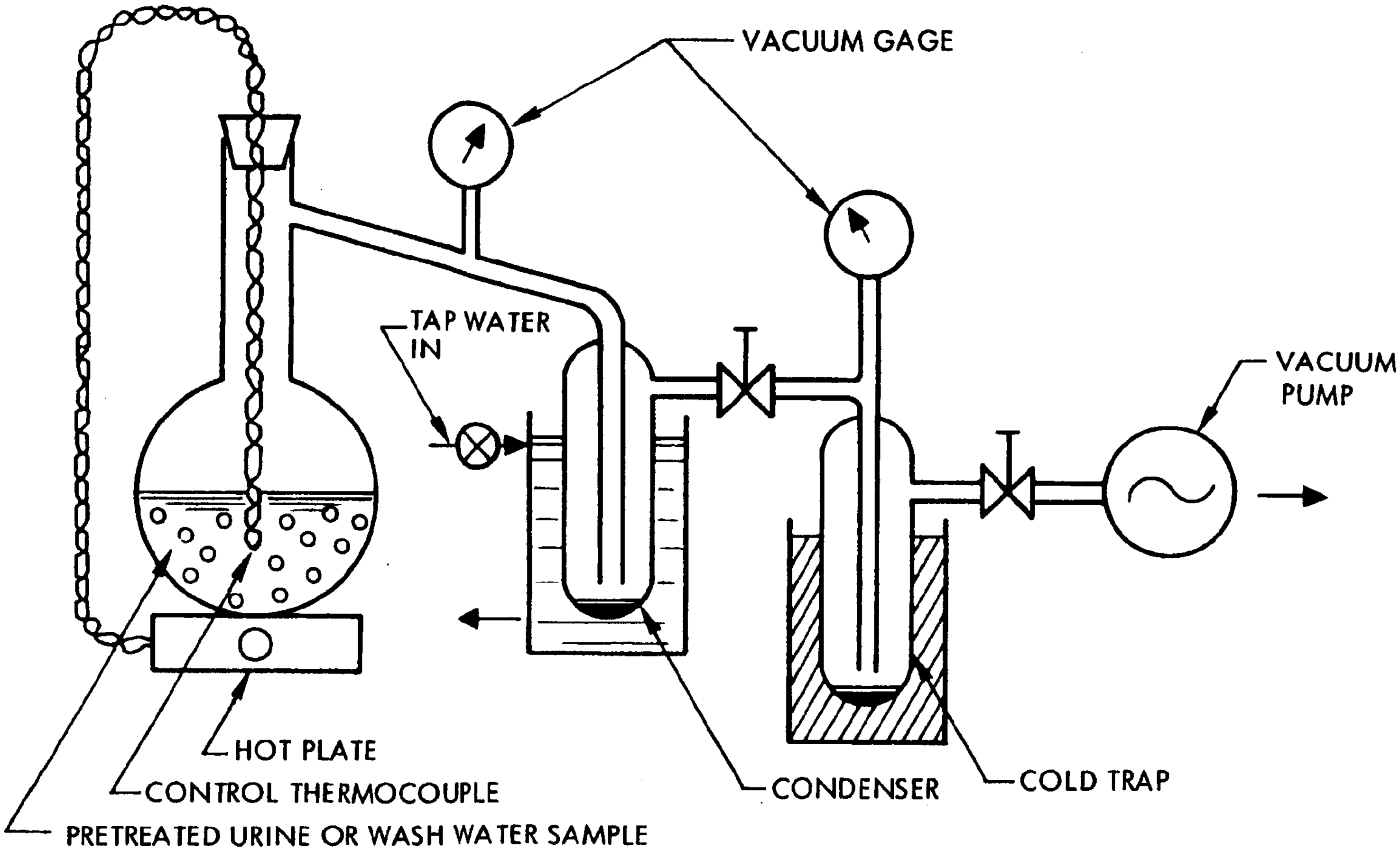


Fig. 3-7 Laboratory Test Schematic For Urine & Wash Water Pretreat Formulation Studies

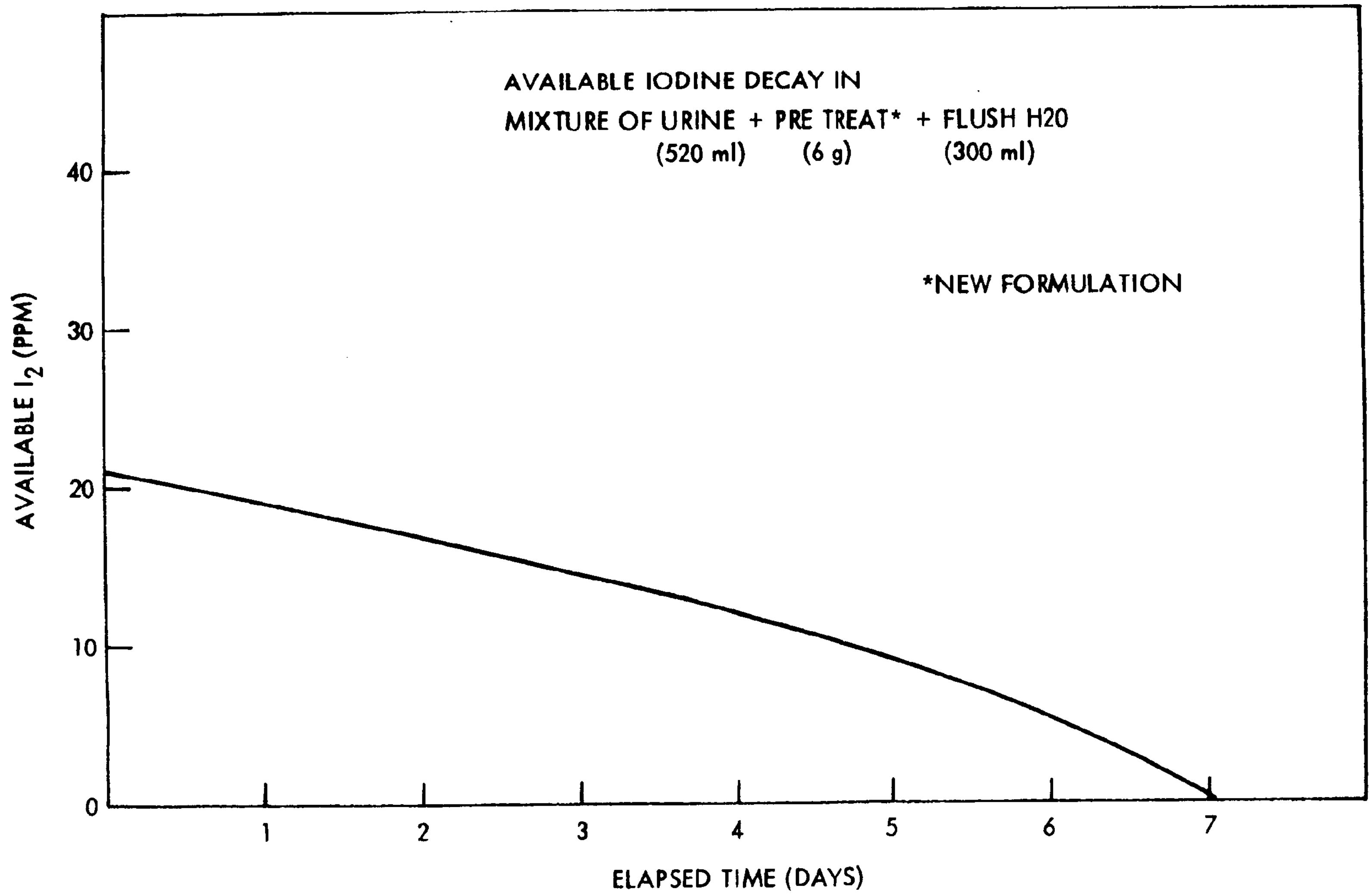


Figure 3-8 Available Iodine Decay in Pretreated Urine and Flush Water

Pretreatment investigations of hyperfiltrated wash water brine were carried out. Soiled wash water is a mixture of effluents from personal hygiene facilities, laundry equipment and galley clean-up equipment. The input to be processed by a distillation unit is a concentrated form of soiled wash water (SWW) produced by a reverse osmosis (RO) processor.*

The following characteristics of SWW and RO brine were noted in previous studies:

1) Cleansing agents account for 80 to 90% of the soluble matter in SWW and RO brine.

2) The concentration of soluble matter in SSW will not exceed 0.3%.

3) The concentration of solute in the RO brine (distillation input) is a function of the water yield (ratio of clean water output to SWW input). At 70 to 90% yield the RO brine solute concentration will not exceed 2.5%.

4) RO brine contains in excess of 10^6 viable micro-organisms/ml.

5) The quantities of germicide used in galley clean-up are insufficient to retard or control microorganism growth in the mixed SSW effluent.

The following characteristics of untreated condensate obtained from VCD processing of RO brine were noted in previous studies:

1) The condensate produced from RO brine typically contained viable microorganisms in the order of 50 to 100/ml.

2) The condensate quality or purity level was inferior to that typically realized with urine brine. The following values were noted; 200 to 300 ppm COD (relatively high organic content), specific resistance of 7,000 to 10,000 ohms/cm (approximately equal to a 500 to 600 ppm salt solution) and alkaline pH values (typical of RO brine).

*Contaminants existing in the Hyperfiltration brine are only those rejected by RO.

The conclusions reached as the result of previous efforts were that off-quality condensate was due to foam induced carry over and co-distillation of volatile organic substances.

Definition of the cleansing agents and their recommended concentrations is vital to development of an effective pretreatment chemical at the minimum weight penalty. Previous studies have used Miranol C2M detergent (used in "no-tears" baby shampoo) and Nutrogena Rain Bath (liquid soap) along with Hyamine and Vanicide BN germicides. The concentrations of these agents are readily calculated from existing data.

Preparation of fluid to test the activity of the pretreatment chemical was necessary. Prior experience with wastes indicated that totally synthetic or artificial waste fluids are unreliable test materials although artificial waste fluids can be useful in preliminary tests.

In anticipation of possession of actual hyperfiltration brine, a synthetic brine was created. This brine, when pretreated at the same ratio as urine/flush water and vacuum distilled in glassware, produced a first fraction condensate yielding 17 ppm dioxane and 57 ppm TOC. No foaming or carryover was noted. Rather than continuing with synthetic brine, some real brine was produced according to the following plan:

After handwashing with 1.89 mm^3 (0.5 gal) water, 6 volunteer LMSC employees wearing specified garments would exercise daily on a bicycle ergometer for a specified duration. They would then shower using 3.78 mm^3 (1 gal) water. After showering, the clothing was machine washed using 11.36 mm^3 (3 gal) water. All the soiled wash water was collected. The soap used in all washings was sodium laurel sulphate and amounted to 2.8 g per man per day. The soiled wash water was then hyperfiltrated through a Model 0440-042 Dupont Permasep commercial reverse osmosis module until 90% recovery was effected. The remaining brine was used for pretreatment development work.

Initial investigations showed that the iodophor constituent in urine pretreat was much too strong for R.O. brine. Accordingly, the amount was reduced to yield at first mixing 20 ppm I_2 as is the case with urine. Unfortunately, the I_2 disappeared within one day. By boosting the iodophor constituent, a rapid time rate of decline of I_2 was observed which settled down on day 4 to a slower rate (same as urine). A fractional vacuum distillation of the boosted mix showed increased I_2 carryover which, however, was responsive to charcoal cleanup. The foaming characteristics reported by earlier investigators did not appear hence no change of antifoam constituent seemed necessary.

Investigating the mechanism of I_2 decline centered on whether it occurred in the aqueous or gaseous phase. A mixture of pretreat and distilled water was made and lost only 4% I_2 in 7 days. It was concluded that I_2 decline in R.O. brine is chemical in nature and is taking place in the aqueous phase. The effect of pH was investigated in I_2 decline and it was found that acid increases I_2, suppresses bacterial growth, and has little or no effect on foaming. Monitoring I_2 decline over a seven day period in pretreated R.O. brine adjusted to pH 3 gave the results shown in Fig. 3-9. It should be noted that I_2 declines rapidly over a three day period then moderately. To achieve an I_2 declination to 0 at day seven would require an initial level of I_2 = 140 ppm. As shown in the lower curve of the same figure, initial I_2 concentration of 20 ppm rapidly goes to zero the first day. Three approaches to R.O. Brine pretreatment seemed to be evolving 1) Pretreat to I_2 = 20 ppm, 2) Pretreat to I_2 = 140 ppm, or 3) Daily redose with Biopal. To help decide which approach to take, case 1) above was stored for seven days and no increase in suspended solids noted. Case 2) was vacuum distilled and carryover noted (TOC = 12 ppm and I_2 = 100 ppm).

On the basis of these data it was concluded that daily dosing should be avoided because of complexities introduced. It was also concluded that the choice of either the ½ day or 7 day available iodine dosing regimen o 470 cc R.O. Brine

475 mg Biopal
4 drop H-10
1 drop A
9 drop H_2SO_4

} pH 3

Day	Date	I_2 (ppm)
0	5/10	205
1	5/11	158
2	5/12	142
3	5/13	94
6	5/16	70
7	5/17	66

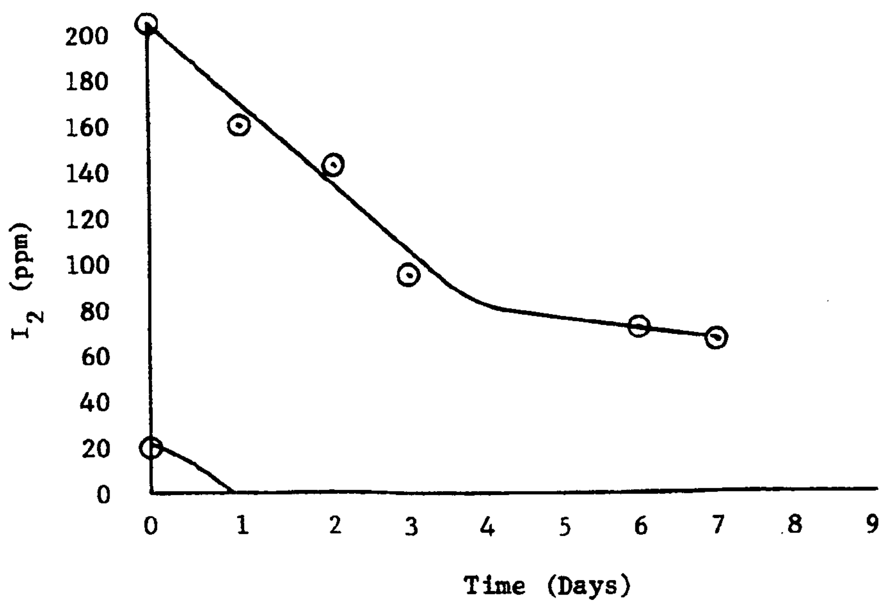


Figure 3-9 Available Iodine Decline in Pretreated R.O. Brine

should be decided on the basis of acceptibility of a charcoal cleanup procedure or the commitment to process the waste stock promptly.

Table 3-4 presents the final R.O. brine pretreat formulations evolved.

As a final test to investigate for hostile synergistic effects of combined pretreated urine/flush water and pretreated R.O. brine, samples of each were prepared and mixed. Preparation was as follows:

1) 3 g urine pretreat mix plus, 260 μm^3 (260 ml) urine plus 150 μm^3 (150 ml) flush water
2) 410 μm^3 (410 cc) R.O. brine plus 294 mg biopal 130 mg antifoam H-10 3 mg antifoam A 250 mg H_2SO_4

One batch was vacuum distilled, and a second batch was stored for 7 days and monitored for I_2 decline. The results of the 10% fractional vacuum distillation are TOC=11 ppm, I_2 = 62 ppm, and dioxane = 13 ppm. The I_2 in the stored batch declined from 25 ppm on day 0 to 3 ppm on day 7.

Chemical Pretreat Metering Unit Development. The laboratory and SSP/VCD system tests of urine and wash water pretreatment chemicals established the system requirements for the metering unit. It has been assumed that the same basic metering unit concept can be used for both urine and wash water except that different flow rates and chemical compositions will require different adjustments. Efforts in this program have concentrated on urine pretreat metering, because the requirements are well established. The urinal used in previous VCD development tests was delivered to LMSC for use in breadboarding the metering unit design. In studying the metering unit concepts various alternatives for the point of injection and the means of injecting the pretreat solution were considered. The objectives were to add the pretreat early, and to achieve a fixed ratio of pretreat solution to urine plus flush water. In order to avoid having to measure the flow of the urine plus flush water, or to measure changes of volume in the waste tank, it was decided to inject the pretreat solution into the urinal each time it is flushed.

Table 3-4

R.O. Brine Pretreat Formulations

	Urine (mg)*	R.O. Brine (mg)**	
		½ day 0 ppm I_2	7 day 0 ppm I_2
Biopal	1230	148	294
Antifoam H-10	130	130	130
Antifoam A	3	3	3
H_2SO_4	340 (pH 3)	290 (pH 3)	250 (pH 3)
Water	1297	-	-

*260 ml urine
150 ml flush water

** 410 ml R.O. Brine

Since a metered amount of pretreat solution and a metered amount of flush water are used, a fixed ratio of these liquids was achieved. Also, adding the germicide in the urinal prevents bacterial growth everywhere downstream.

Several means of delivering metered quantities of liquid were studied. One of these was an aliquot dispenser. Such a device was designed, built and tested by LMSC and delivered to NASA Langley Research Center for their Orbiting Primate Experiment. It was successfully used to dispense metered quantities of drinking water to monkeys upon demand. A similar device could have been used for this project, but would be more costly than the favored approach.

Another method of delivering a given quantity of liquid is to feed the liquid through an orifice or similar constriction, using a known feed pressure, and a preset flow duration. The latter can be achieved by opening a normally closed solenoid valve for the desired amount of time. This method is the favored one for dispensing 150 μm^3 (150 ml) of flush water in 4 seconds. However, it might not be sufficiently accurate to dispense 3 g of pretreat solution. The proposed device for accomplishing the pretreat addition utilizes a diaphragm type chemical metering pump. Precision Control Products Corporation metering pump model S 12004A can be adjusted to deliver from 0.35 to 3.5 μm^3 (0.35 to 3.5 ml) per stroke at pressures up to 620 kNm^{-2} (90 psi). This pump is made of materials which are highly resistant to corrosive agents such as sulfuric acid.

Figure 3-10 is a schematic diagram of the first version pretreat metering unit. The chemical solution is stored in a metal bellows tank. After each micturation the user presses a double pole switch. One pole actuates the metering pump which dispenses 3 g of pretreat solution. The other pole energizes a solenoid valve for 4 seconds by means of a time delay. The orifice is sized to pass 150 μm^3 (150 ml) of flush water during these 4 seconds.

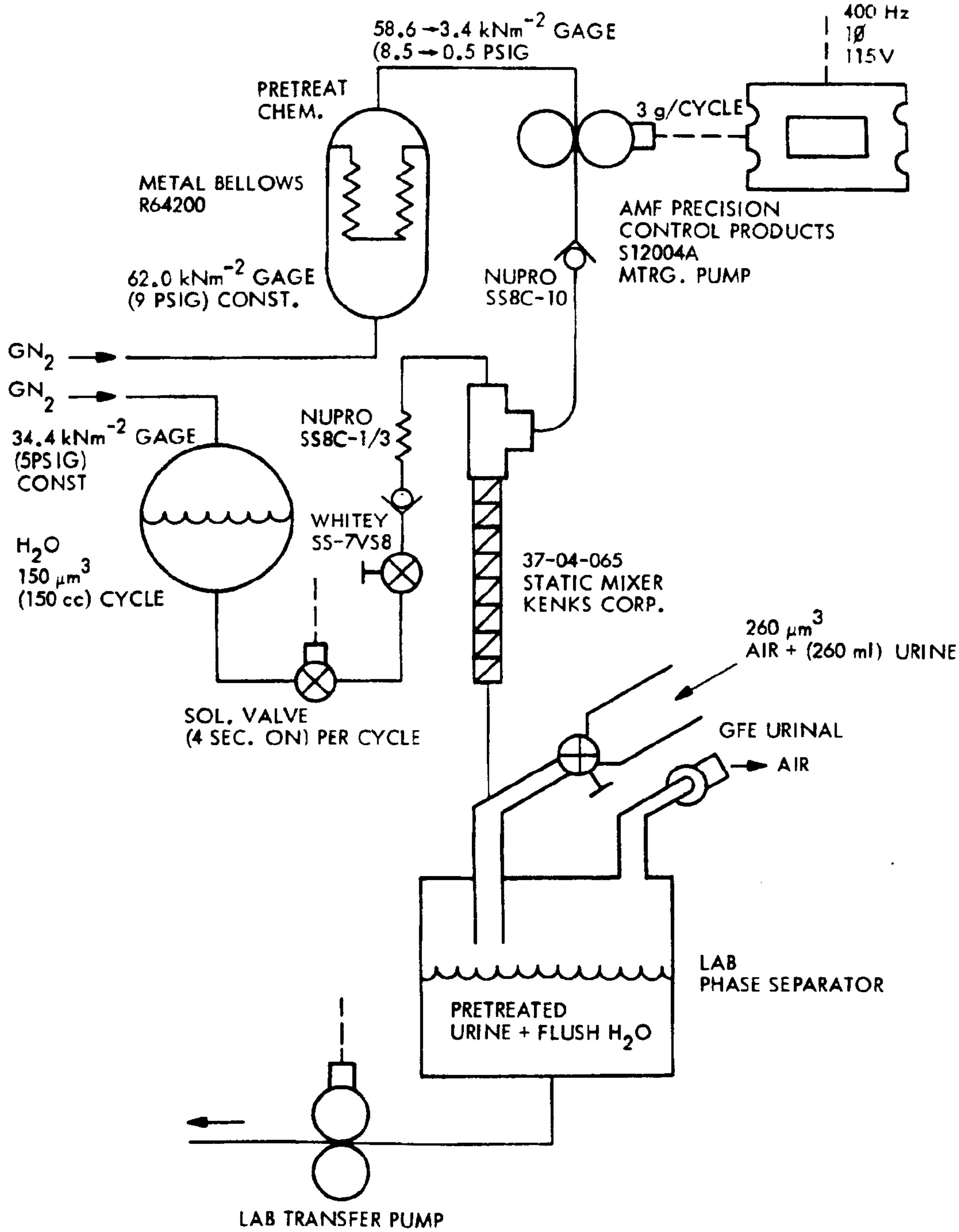


Figure 3-10 Pretreat Metering Unit First Version

The pretreat chemical and flush water join each other and are mixed in a static mixer (Kenics Corp. Model 37-04-065). This device utilizes a series of fixed helical elements enclosed within a tubular housing. The fixed geometric design of the unit produces unique patterns of flow division and radial mixing simultaneously. In laminar flow a processed material divides itself at the leading edge of each element and follows the channels created by the element shape. At each succeeding element the two channels are further divided, resulting in an exponential increase in stratification. The number of striations produced is 2^n where n is the number of elements.

The mixed pretreat chemical and flush water continue on and connect to the base of the urinal flushing urine on to a one-g laboratory phase separator. This phase separator uses a fan to create a partial vacuum drawing fluids from both the urinal and the pretreat/flush lines into the unit.

A small laboratory transfer pump then delivers the combined liquids into the next subsystem which in this case is VCD.

It soon became obvious that a single pass static mixer was not going to do a sufficiently adequate mixing job, so the flow paths were rearranged as shown in Figure 3-11. In this version, a start button is pushed at completion of urination. Urine is flushed out of the urinal by a timed release of flush water through a metering solenoid valve. During this same time period, 3 g of pretreat chemical is dispensed into the flow stream. The transfer pump is energized and a 3-way valve recycles its output in a closed path through the 1 g phase separator and the static mixer. After a number of cycles has transpired, the thoroughly mixed pretreated urine and flush water is directed to the next subsystem. This unit was successfully tested and delivered. Output from the PMU was used in available iodine studies and as input to glassware vacuum distillation tests.

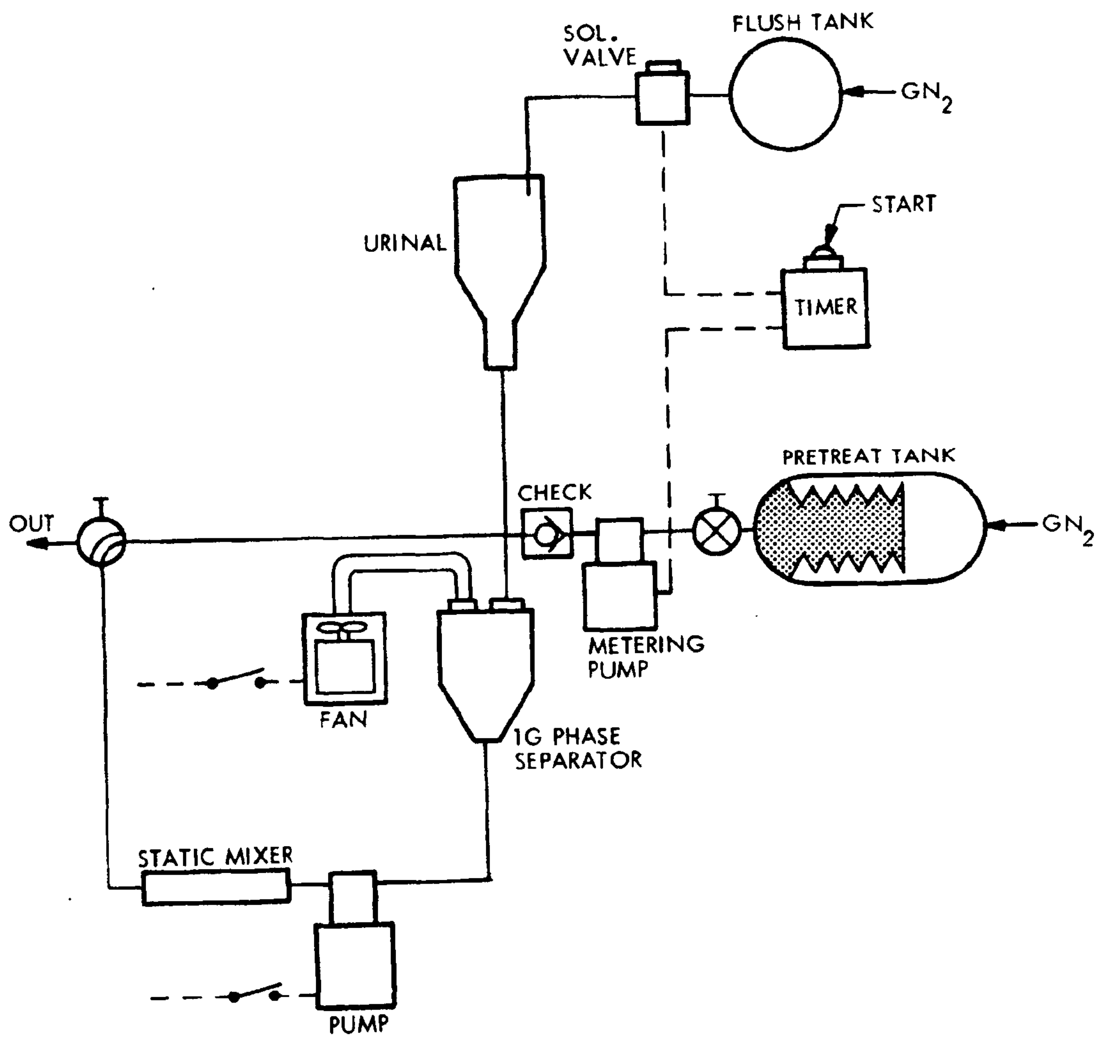


Figure 3-11 Breadboard Pretreat Metering Unit

The recommended PMU for urine and R.O. brine shown in Figure 3-12 is somewhat more complicated owing to the differing chemical composition of the two pretreatments. The basic difference between the two formulations is in the Biopal constituent. Accordingly Biopal is contained separately and metered separately. The quantity of Biopal dispensed per event is varied according to whether urine or R.O. brine is to be pretreated. During a urination, the fan, urine separator, Biopal pump, acid/antifoam pump, and the flush water shutoff valve are controlled by a timer. Biopal and Acid/antifoam are added during, and flush water after urination.

Anytime that the urinal and R.O. brine transfer are stopped and an I_2 sensor in the VCD waste tank outlet reads below 10 ppm, the I_2 control pump and Biopal Pump are energized along with the urine separator and fan. This provides the mixing action of the breadboard unit and automatically maintains effective bacterial control no matter what waste stock is injected.

On high R.O. brine storage tank signal, R.O. brine is transferred through the urine separator with Biopal and Acid/antifoam being added simultaneously.

3.5 Waste Tank Development

A variable capacity waste tank is necessary to accommodate both the intermittent inflow from the waste collectors and the nearly steady-state outflow of the distillation unit. A small positive pressure, 34.5 kNm^{-2} (5 psig) is maintained inside the tank to permit effective operation of the waste collectors. Probably the best developed and most reliable zero-g tank with two-phase capability is the single bladder configuration in which the bladder contour is uncontrolled except in the extreme-empty and extreme-full conditions. Regulated gas pressure is applied on one side of the flexible bladder with the liquid volume on the other side. The barrier between the two fluids assures expulsion of only liquid at the liquid port and only gas at the gas port.

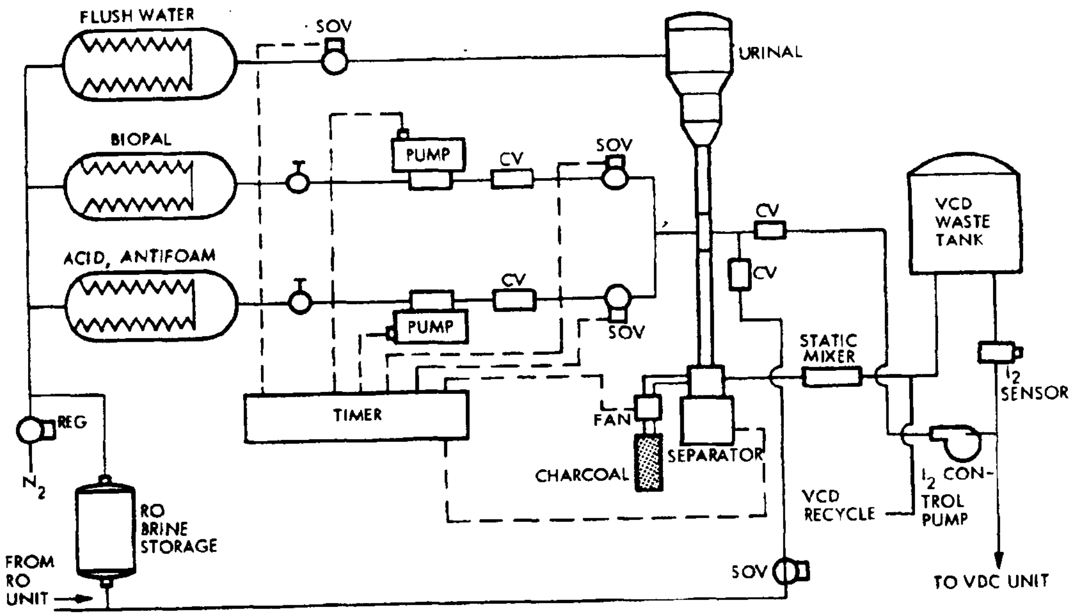


Figure 3-12 Recommended Urine & R.O. Brine Pretreat Metering System

For the SSP, automatic starting and stopping of the distillation process was made a function of liquid volume present in the waste tank. It was necessary, therefore, to incorporate a quantity-measuring device in the tank. The configuration selected included a guided piston to maintain the contour of the flexible diaphragm. Variable liquid volumes resulted in a predictable and measurable displacement of the piston. Satisfactory operation of the SSP/VCD tank was achieved, but the following limitations existed.

1) Total tank volume is approximately twice the liquid capacity to accommodate the traveling piston and related mechanism, therefore tankage empty weight is significantly greater than is necessary to contain only the liquid.
2) Complexity of the tank/quantity gage assembly is greater than should be necessary for the application.
3) Inadvertent application of gas pressure at the liquid port or pressurizing the tank chambers in the wrong sequence has caused the rupture of three bladders.

Some simplification could have been made to the SSP waste tank design, especially in quantity measurement. Backstopping surfaces could have been added to support the bladder should it be loaded by accidental application of reverse pressure, but further development of the SSP/VCD waste tank was not the best solution.

Early in the preprototype development other concepts were evaluated. Certain ground rules were established to normalize the various concepts.

1. Must hold 18.2 kg (40 lbs) of waste water at pH = 2
2. Pressure range 13.8 - 68.9 kNm^{-2} (2-10 psig)
3. Must work in zero-g
4. Must not contaminate water cause corrosion
5. Must provide signals when 3.62 kg (8 lb.) or 0.36 kg (0.8 lb) remain in tank, or when tank is full.
6. Cabin pressure 101.4 kNm^{-2} abs. (14.7 psia)
7. Tank temperature 15.5-26.7°C (60-80°F)

Three categories of concepts were considered.

Category A: Bladdered tanks with three discrete outputs.

Category B: Bladdered tanks yielding $\pm$10-20% analog volumetric accuracy.

Category C: Bladdered tanks yielding $\pm$ 5% analog volumetric accuracy.

Concepts involving pistons were not considered.

The first concept considered in Category A consisted of a 3.62 kg (8 lb) bladder tank pressurized at 34.4 kNm^{-2} gage (5 psig) and a 14.53 kg (32 lb) bladder tank pressurized at 41.4 kNm^{-2} gage (6 psig) connected in parallel to the waste line. In the waste line is a pressure transducer (or switches) Wastes would always fill the smaller tank first and empty it last because of its lower pressure. The pressure in the waste line would indicate the quantity in both tanks according to the following:

Table 3-5 Pressure/Volume Relationship

Tank Condition		Pressure		Water Quantity	
Small	Large	kNm^{-2} gage	(psig)	kg	(lb)
Empty	Empty	$P<34.4$	$(P<5)$	$W = 0$	$(W=0)$
Part Full	Empty	$P=34.4$	$(P=5)$	$0<W<3.62$	$(0<W<8)$
Full	Empty	$34.4< P< 41.4$	$(5<P<6)$	$W = 3.62$	$(W=8)$
Full	Part Full	$P=41.4$	$(P=6)$	$3.62<W<18.16$	$(8<W<40)$
Full	Full	P 41.4	$(P>6)$	$W=18.16$	$W=18.16$

The advantages of this concept are: standard tanks are used, it is simple and reliable, and not affected by temperature or cabin pressure. The disadvantages are: that only 3 discrete quantity points are available, two tanks are required, and that some gas is wasted during cycling.

A variation of this same concept places a window in the upper pressurant section of the larger tank. Visual access to the bladder state permits assessment of waste volume. All the above advantages are retained while countering the disadvantage of only discrete quantity points. However additional disadvantages arise in that a special tank (with window) is required, astronaut involvement is required, and intermediate quantity assessments require training and judgement.

Only one concept in category B was considered. In this concept, a doubler vulcanized to the bladder provided a tethering point for a spring returned rotary potentiometer located in the pressurant area. Recognizing the shortcomings of an unguided bladder, it was felt that enough self guidance would exist to provide a repeatable displacement to yield ±10-20% accuracy. The advantages of simplicity, not being affected by temperature or cabin pressure would be augmented by continuous readout capability. The disadvantages including only fair accuracy as mentioned above are: a special bladder with attachment point required, a non standard tank might be required to accommodate the attachment, a possibility of bladder damage due to internal parts, and lastly some gas is wasted during cycling.

In category C, four concepts were considered. The first (C1) utilized a bladder tank with trapped gas pressurant monitored by an absolute pressure transducer. As the tank fills, the trapped pressure rises and indicates the quantity. The advantages are: simplicity, good accuracy (±5%), use of a standard tank, gas not wasted, the measurement is not affected by cabin pressure, and continuous readout is given. The disadvantages are: a larger tank is required, temperature changes affect readout, the delivery pressure varies with liquid volume in tank and cabin pressure, and gas leakage affects accuracy.

The second concept studied (C2) utilizes a bladdered tank where the volume of gas on the pressurant side would be ascertained on some arbitrary schedule by measuring the time interval required for the gas pressure to decay a calibrated delta pressure through a calibrated orifice. Makeup gas would be excluded during the actual measurement. Accuracy would be ±5% and due to the small decay necessary, only 0.45 g (0.001 lb) would be lost per measurement. Disadvantages of this concept include: cycling required at each readout, slightly affected by changes in temperature or cabin pressure, affected by dirt in the orifice, an electronic circuit required, and gas lost during cycling and blowdown.

The third concept (C3) utilized direct gaging by radiation. A sendor is located near the fluid outlet and a receiver diametrically opposite. An electronic controller converts the received radiation signal to a waste quantity. Systems of this nature have been developed and flown yielding $\pm 3\%$ accuracy when full and $\pm 0.3\%$ accuracy when empty. Power requirements are less than 3W. The Krypton 85 gas source provides low level gamma radiation which would not make the wastes radioactive. At 60.9 cm (2 ft), the radiation level is 516 $mCkg^{-1}/hr$ (2mR/hr). The advantages of this concept are that a standard tank is used, a proven flight qualified available readout exists, continuous readings are given, and cabin temperature and pressure variations do not affect readouts. Disadvantages include the normal dislike of radiation sources within a cabin, gas is wasted during cycling, electronics are required, and the system is fairly expensive.

The fourth concept (C4) in this category uses a reversible liquid flow meter in the waste line which maintains a running algebraic sum of waste quantity. When the tank is full or empty (as indicated by fluid pressures, monitored by a transducer or switches, either exceeding or falling below gas pressure) the reversible flow meter is updated. Advantages of this concept include usage of a standard tank, continuous readout given, and readout not affected by cabin temperature or pressure. Disadvantages include drift or loss of accuracy if tank is not filled or emptied regularly, a susceptibility to dirt or solids in the waste water, fair complexity, and possible need to develop a special flow meter.

At the first program review, it was decided to abandon the SSP waste tank concept and pursue a bladder waste tank concept utilizing either radiation or bleed down gaging techniques. Before radiation gaging could be accepted within a manned system, an assessment of the risks was to be made. Such an assessment was made, and the results presented in Appendix B. The conclusion reached was that the radioisotope tank level gage is a safe device.

While surveying tank suppliers, it was determined that Space Shuttle was using a metal bellows tank for urine storage. This concept was investigated concurrently with the search for a suitable bladder tank. The metal bellows concept utilizes the same principle for waste measurement as the present SSP tank, i.e. a lanyard operated potentiometer. The chief difficulty of rolling bladder reversal is eliminated by exchanging this element for a bellows. Preliminary designs were prepared, and later when bladdered tank sources proved fruitless, a purchase order was let for a metal bellows tank (Model 75287 Metal Bellows Corp., Chatsworth, California).

This tank has a metal bellows constructed of inconel 718 by cutting and forming rippled doughnut shaped pieces from thin sheetstock and welding a nested stack of sheets on both inner and outer diameters at every other sheet pair. The resultant bellows folds very closely in the closed condition much like an accordian. A curved head on the pressurant side is guided in its excursion by slippers and comes to rest on bumpers at its upward stroke. A conventional lanyard-extended spring-return rotary potentiometer tracks the bellows position. The base of the bellows contains two ports for fluid inlet/outlet.

Surrounding the bellows and giving support to the base, slippers, bumpers, and potentiometer is an aluminum shell containing the electrical and gas interfaces in a removable port on the upper end, and threaded mounting lugs on the lower end. This type of tankage has been used since 1955 for many purposes. The fact that Space Shuttle was using one for urine storage was pivotal in deciding to adopt this design. One drawback is that the bellows is intrinsically a spring and has a spring rate which either adds or subtracts from the gas pressure as waste quantity changes. Typically, the bellows is held to an intermediate length while it is annealed. This length then becomes the null position, and the fluid pressure excursion then "straddles" gas pressure.

Due to the fact that so much similarity existed between the Shuttle tank and the VCD specification, manufacturing opportunities permitted delivery of the waste tank 2 months ahead of schedule. Upon receipt of the tank, a calibration was performed using regulated dry nitrogen as pressurant, and tap water as fluid. Various weights and potentiometer resistances were recorded including dry, dry with pressurant, pressurized empty with water added until bubbles stop, then a series of fillings and emptyings, until repeatability was established. The expulsion ratio was 0.953. With 34.4 kNm^{-2} gage (5 psig) gas pressure applied at the bellows null position, the waste fluid pressure varies from 21.4 to 46.9 kNm^{-2} gage (3.1 to 6.8 psig). Calibration data was used to set control points in the VCD controller. The tank was mounted in the VCD module as shown in Figure 3-13.

When preparing for the first VCD run, a leak was noted in the bellows. The tank was returned to vendor for repair. The vendor opened the tank and found a small hole 0.81 mm (0.032 in) dia. approximately half way from inner and outer diameter of one convolution at a mid-bellows location. The hole appeared to be the result of corrosion. The area surrounding the hole was analyzed qualitatively by wavelength dispersion x-ray spectroscopy. Major oxygen and aluminum and minor nickel concentrations were found in the corroded area. In a nearby non-corroded area moderate oxygen, minor aluminum, and major nickel concentrations were found. In both areas, only traces of mercury were found. The vendor postulates two different electrolytic corrosion mechanisms involving mercury, aluminum, inconel base, and mildly acid tap water. Both the vendor and LMSC are unable to determine the actual cause of corrosion, and the vendor indicates never experiencing this type of problem before.

A new bellows was fabricated and installed in the tank and the tank assembly returned to LMSC. Upon receipt of the tank, another calibration was performed, and the tank put in service. Since the tank has been in service, it has performed excellently with all types of wastestock.

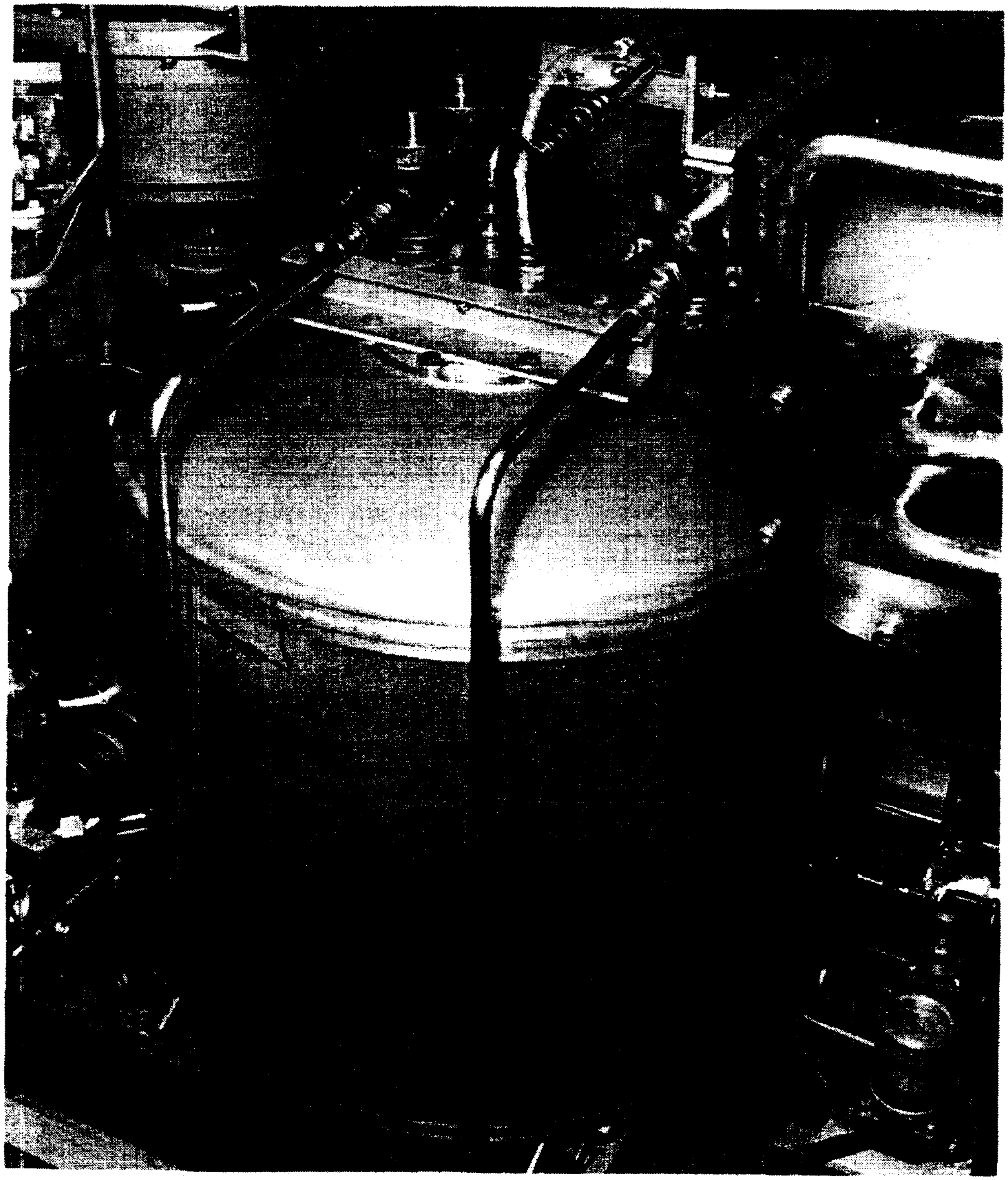


Figure 3-13 VCD Metal Bellows Waste Tank

3.6 Drive Line Development

The only energy input required by the distillation unit is that to rotate the compressor and the centrifuge. In the SSP configuration, these loads were driven by a conventional 3-phase induction motor. To simplify changing a faulty motor in flight, it was located outside the stationary shell. A synchronous-speed magnetic coupling was applied at the shell interface in lieu of a shaft penetration to avoid the power loss and potential in-leakage characteristic of dynamic seals. That arrangement was adopted for SSP as a low cost solution to providing the desired motor accessibility. Several limitations to this approach existed. They are:

1) While the driven magnet could be mounted directly to the driven shaft, the driver magnet had to be carried in separate bearings because its mass was too great to be cantilevered off the motor shaft. Those bearings had to be large in diameter and dissipated more than a negligible portion of motor power.

2) A significant weight penalty is imposed by the magnetic coupling assembly. The magnet material is dense, the magnets are large and the support housing is necessarily larger.

3) The torque transmitting capacity of the synchronous coupling is limited to a single level independent of speed. Unlike an induction coupling, increased torque does not decrease speed, but rather at the limiting torque level the coupling opens, and the driven load comes to a stop. For the SSP that limiting torque was designed and measured at 0.75 Nm (105 oz-in), forty percent higher than the maximum motor output torque. After extended idle storage and delivery to NASA the coupling limit torque had decreased (for a reason not yet understood) to a level lower than maximum motor torque. No coupling openings were experienced during normal operation, but immediately after re-lubricating the bearings and gears the viscous loads were often so great that uncoupling occurred. That failure is more than a nuisance, particularly if magnetic force decay is only a time-dependent phenomenon.

Realizing that a magnetic coupling with the preferred speed/torque characteristics already exists within the motor, the initial approach was to resolve the limitations and problems by integrating the motor and coupling into what is called a "canned" motor. The motor rotor would be placed within the still and the stator outside. A 316 stainless steel sleeve, which is part of the still shell, would lie between the two motor elements, just as the present sleeve lies between the two dynamic magnets.

The least reliable elements of 3-phase inducation motors are the wound stator and the bearings. No internal starting switches or brushes are necessary. As planned, the rotor bearings would be eliminated. The rotor would be cantilevered from the compressor shaft, exactly as the driven magnet is cantilevered in the SSP design. The stator would remain externally located where it is accessible both for replacement without "opening" the still and, more importantly, where it can be cooled by forced convection. The stator should not be located within the evacuated still because cooling of the windings would require elaborate mechanism.

The external buckling pressure taken together with sleeve geometry and material properties resulted in an initial sleeve design of 31.8 mm (1.25 in) diameter by 76.2 mm (3.0 in) long with a wall thickness of 0.102 mm (0.004 in) fabricated of 316 stainless steel. The minimum practical achievable air gap between sleeve and rotor was set at 0.05 mm (0.002 in). These values were used to evaluate motor efficiency loss. Careful evaluation was necessary to avoid losing more input power at that interface than is gained by eliminating bearing losses and reducing drive weight.

As a result of discussions with vendors experienced in production of "canned" motors used on Apollo and EWACS glycol pumps, the greatest overall efficiency predicted was 50-55 percent. This fell short of the goal of 64 percent, but was equal to or slightly better than the existing SSP motor alone efficiency of 50.5 percent. At this point a comparison of the advantages and disadvantages indicated that a canned motor would incur higher development risks with no clear cut power savings. A decision was then made to undertake procurement of a high efficiency external motor driving the compressor through an improved magnetic coupling. In designing an improved magnetic coupling, rare earth magnetic materials were considered.

These materials, notably Samarium-Cobalt, exhibit much greater magnetic properties than conventional ceramic magnets.

Table 3-6

Comparison of Magnetic Properties

Material	Peak Energy Product TAm^{-1} (gauss oersted)		Coercive Force kAm^{-1} (oersted)	
Indox 1	79.6	($1x10^6$)	14.5	(1825)
Indox 6	194.9	($2.45x10^6$)	22.2	(2800)
Samarium-Cobalt	1193-1432	($15\text{-}18x10^6$)	55.7-63.7	(7000-8000)

Peak energy product is a measure of the magnetic strength of a magnet. Coercive force is a measure of a magnet's resistance to demagnetization.

The final magnetic coupling design resulted in an inner magnetic rotor 64 mm (2.52 in) diameter by 40.6 mm (1.6 in) long supported by the compressor bearings. The outer magnet has a bore of 68.3 mm (2.69 in) and is supported by a dual row ball bearing. The radial air gap between magnets of 2.1 mm (0.085 in) is partly occupied by the environmental sleeve thickness of 0.38 mm (0.015 in). The remainder is distributed between inner and outer dynamic clearances. Specified torque of the coupling was 2.824 Nm (400 oz-in) but as delivered measured 3.39 Nm (480 oz-in). As the design of the magnetic coupling proceeded, the opportunity to return to a "canned" motor approach presented itself. Previously, an induction type motor was being considered. In these motors, the efficiency is extremely sensitive to air gap. Having made the commitment to a permanent magnet rotor, the possibility existed to drive this rotor with a brushless direct current stator. Brushless DC permanent magnet rotor motors are less sensitive to the magnetic air gap than induction motors. The reason being that the magnetic flux must be induced in an induction motor rotor but already exists in the permanent magnet rotor. Other advantages, besides larger air gap operation, include: higher starting and stall torques and greater efficiencies. A supplier was placed under contract to design and build to specification a Brushless DC permanent magnet rotor motor and a Samarium-Cobalt magnetic coupling both of which would interchangeably drive the same inner rotor through the same environmental sleeve. The magnetic coupling design permits running the still with any available motor. A preliminary study of this drive concept evolved a transistorized commutation method using Hall effect sensors to sense rotor position. The preliminary calculations indicated an overall 85% efficiency was possible dependent on the material of the sleeve. LEXAN or MACOR would be the best sleeve material from an eddy current loss standpoint (0 Watts). AISI 316 stainless steel would incur a 4 Watt loss, and titanium somewhere between. Titanium was selected instead of the frangible LEXAN or MACOR and the design proceeded.

The manufacturer reported dynomometer test efficiencies of 66% at rated load and 72% at maximum sustained load with the titanium sleeve in place. The predicted eddy current loss of 0 to 4 W in actuality was 16.1 W. Part of this increase was due to the 2.5 mm (0.100 in) thickness of the end of the sleeve. Other factors which decreased performance were the unavailability of both plus and minus supply voltage, and increased parts count in the logic circuitry.

Upon first trial of the drive motor on the still, excessive mechanical load caused failure of the output transistors. The motor was repaired and a load limiting resistor installed. Figures 3-14 through 3-18 show the progressive disassembly of the drive motor. Figure 3-14 shows the complete drive motor mounted on the end plate of the still. Changeout of the motor or substitution of the magnetic coupling is accomplished by removing 6 mounting screws.

Figure 3-15 shows the same assembly with the drive motor stator removed revealing the titanium hermetic sleeve. Figure 3-16 shows the permanent magnet inner rotor revealed by removal of the titanium hermetic sleeve. Also visible in this figure are the compressor timing gears.

Figure 3-17 shows an internal end view of the titanium hermetic shell. Figure 3-18 shows from left to right, the removable magnetic coupling, the permanent magnet rotor, and the stator.

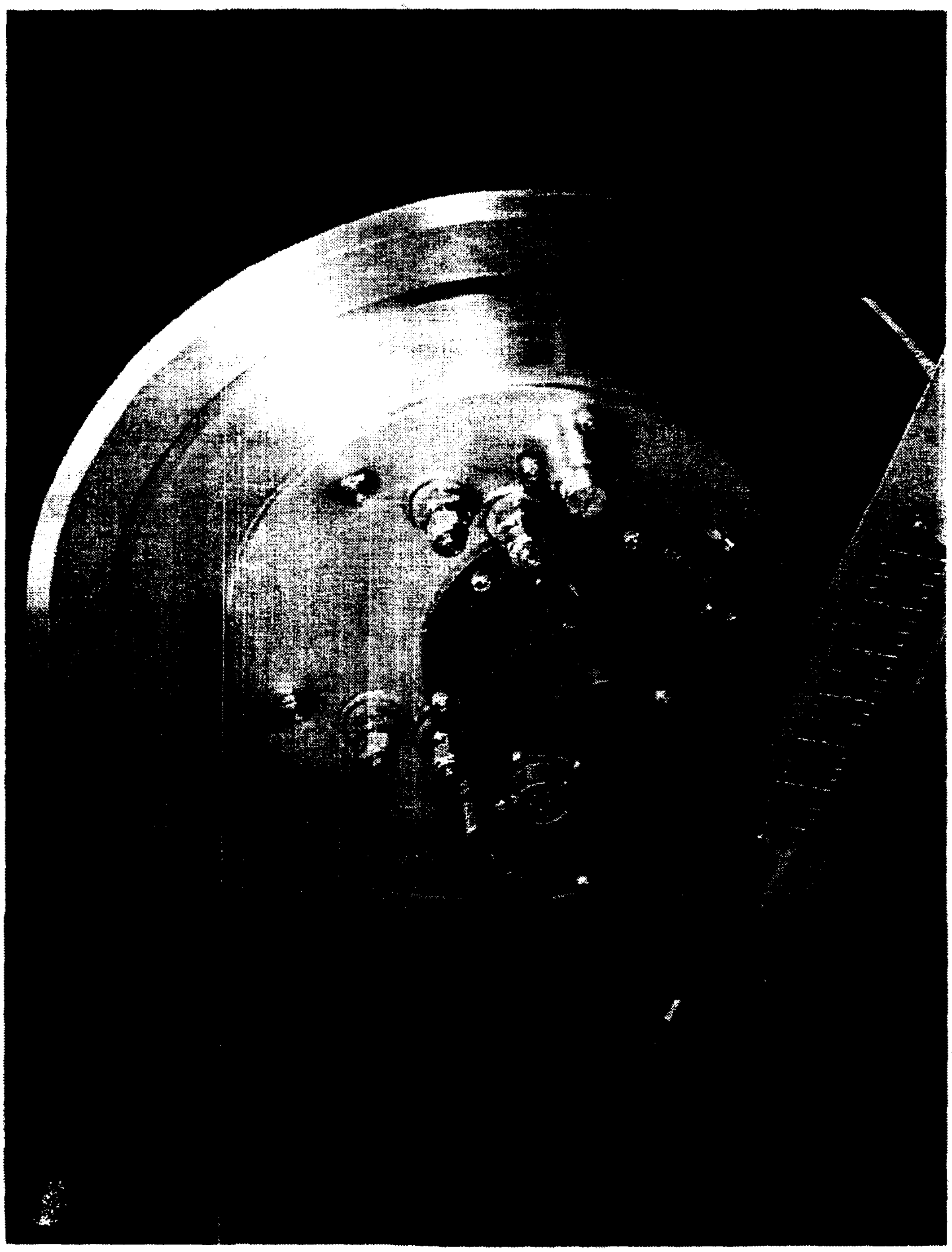


Figure 3-14 Compressor Drive Motor In Place

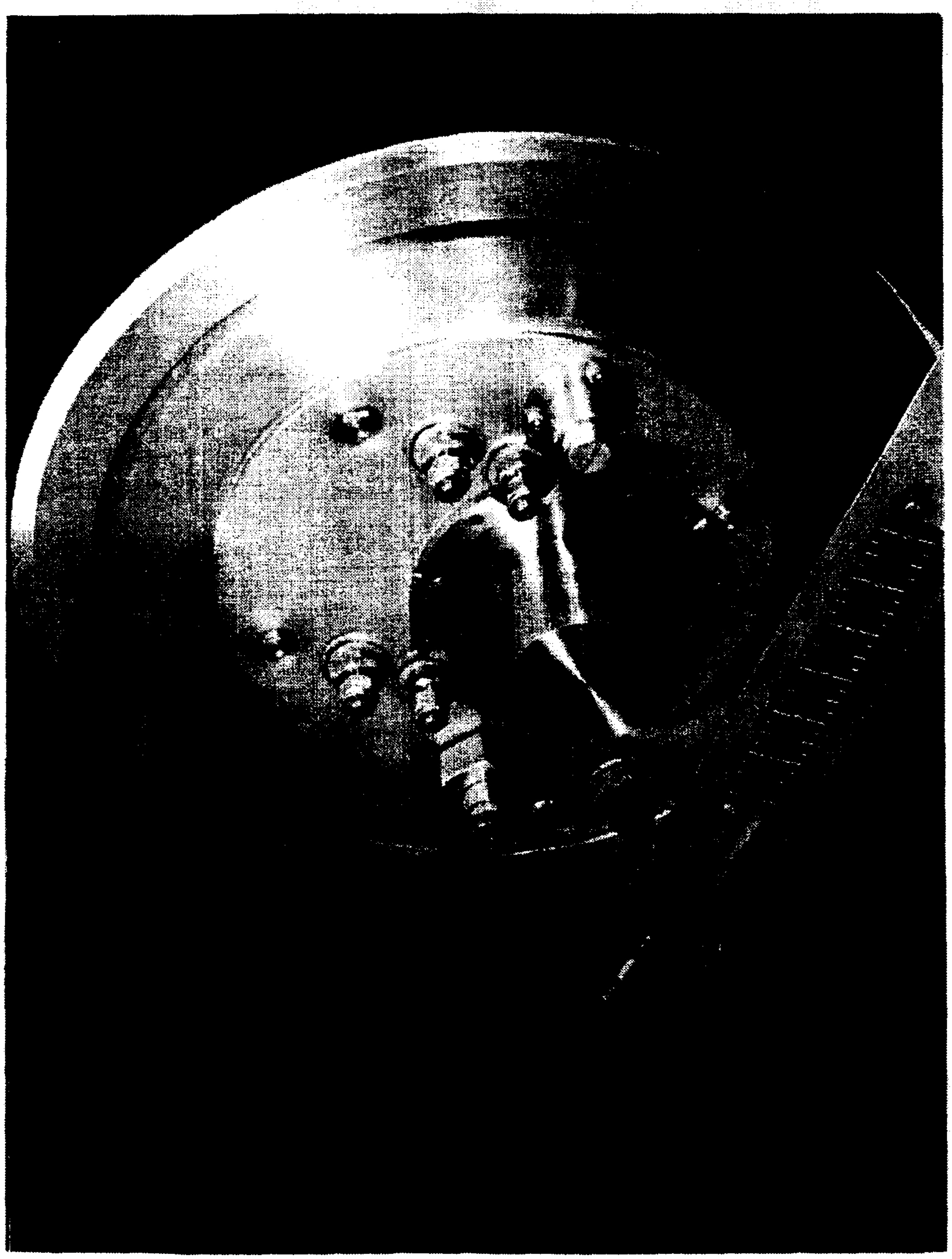


Figure 3-15 Compressor Drive Motor With Stator Removed

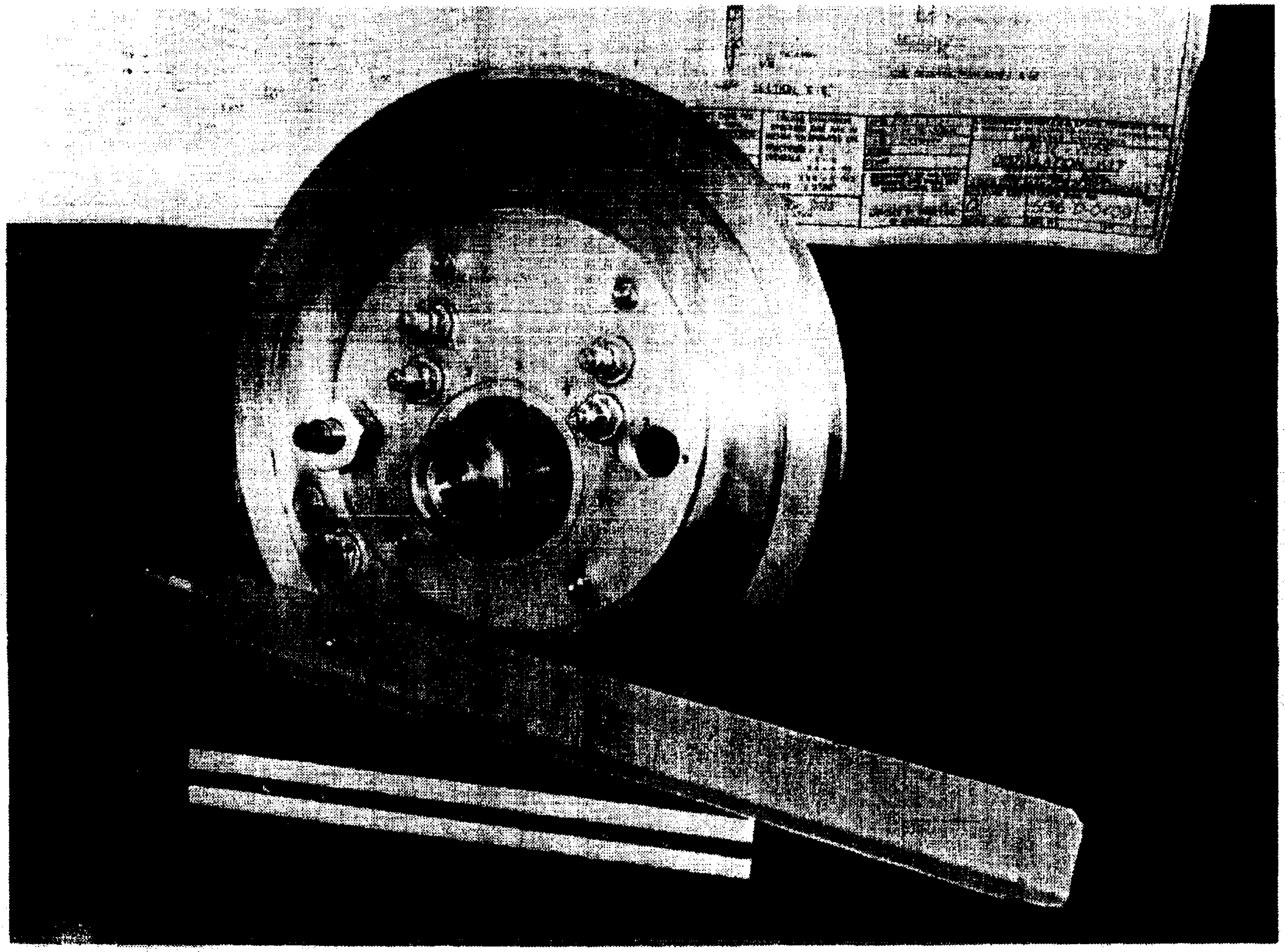


Figure 3-16 Compressor Drive Motor with Stator and Hermetic Sleeve Removed

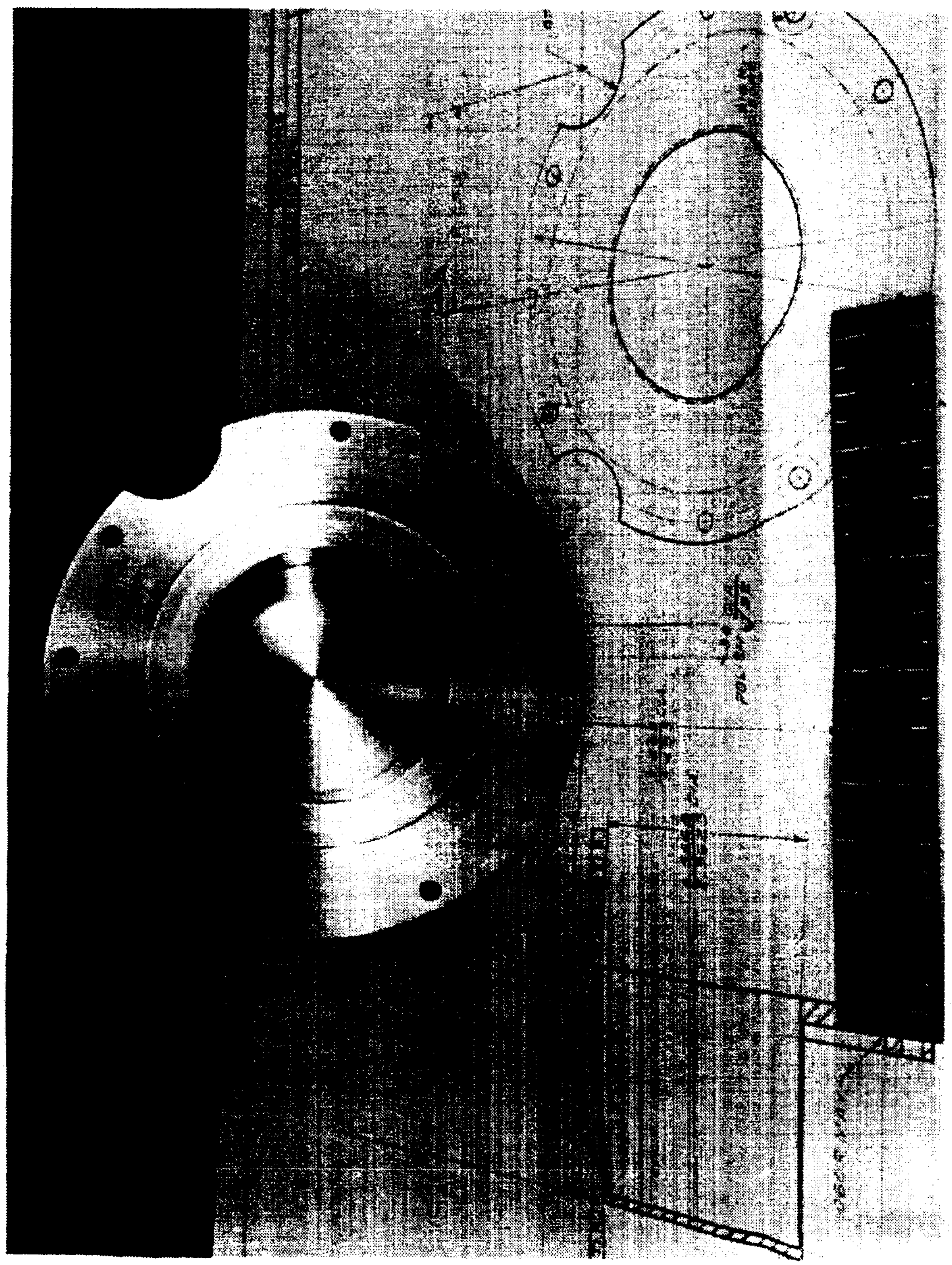


Figure 3-17 Compressor Drive Motor Hermetic Sleeve

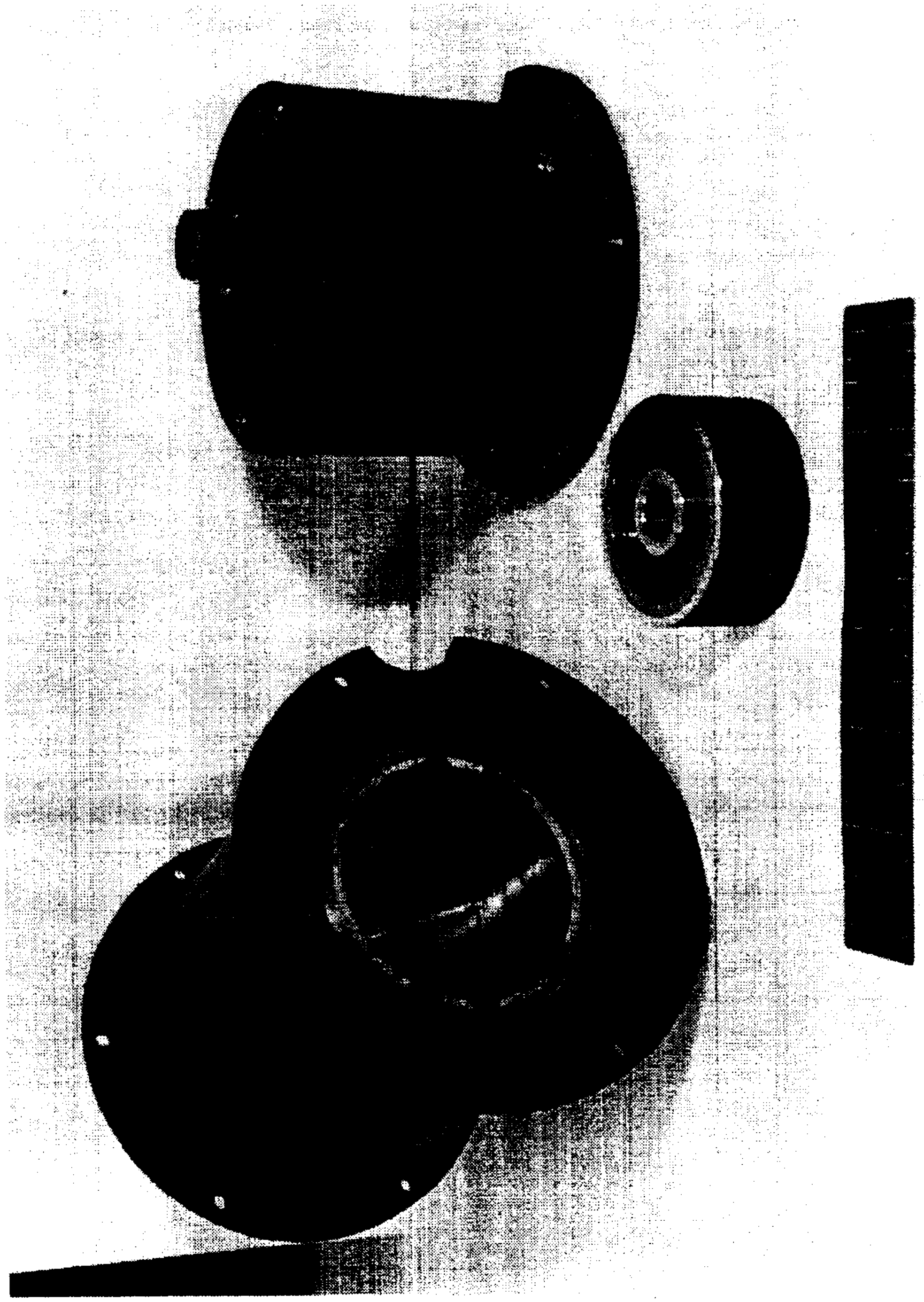


Figure 3-18 Compressor Drive Motor Components

3.7 Vapor Compression Distillation Unit Development

For the distillation unit built in 1973, designated the "SSP Version", emphasis was placed upon ancillary equipment and systems integration, thus only a few design modifications were made to the still. Those modifications included:

1. The demister, located over the compressor inlet holes to exclude droplets from the vapor stream was made to rotate.
2. The centrifuge final drive element was changed from a single o-ring to three (3) smaller diameter o-rings operating in parallel.
3. In an effort to increase the overall heat transfer coefficient, the centrifuge speed was increased by approximately 25%.
4. The drive motor was located external to the still envelope where it was accessible for replacement without repressurizing and opening the distillation unit. Coupling the motor to the internal load was accomplished across a light-gage stainless steel membrane via a zero-slip magnetic interface.
5. A rudimentary centrifuge speed sensor and boiler temperature sensor were added.
6. All parts previously made of aluminum were made of stainless steel.

Subsequent test experience with the SSP version showed that some of the design modifications were valuable improvements, but weaknesses were discovered as well. The RLSE program presented an opportunity to correct weaknesses and to make other design changes not permitted in the SSP effort. SSP test experience led to component evaluation and modifications as follows:

1. Some improvement in water quality was measured and attributed to the rotating demister built for the SSP version, but a significant mechanical load was imposed by a bearing located at the rotating interface. For the RLSE unit the rotating demister concept was retained, but the demister was cantilever-mounted from the boiler structure to eliminate the bearing and the associated power dissipation. Residue, the positive indicator of carryover was present downstream of the demister after the RLSE still had been run with R.O. brine, but when stills fitted with stationary demisters were operated with R.O. brine the carryover was so severe that the compressor was stalled and caused failure of the drive motor. It must be concluded that rotating demisters reduce carryover when distilling high-foaming waste, but that better chemistry-oriented control over foaming is necessary to eliminate carryover.

2. The triple o-ring drive operated without failure in the SSP version, but three belts are redundant. Each of three pairs of pulley grooves, though made to close tolerances, must necessarily exhibit somewhat different pitch diameter ratios; each of the three parallel drives, therefore, urges the centrifuge to run at a somewhat different speed - which, of course, is impossible. That speed discrepancy is cumulative with each revolution, and continuous slipping must occur on at least two of the three belts. Should that slipping cause one belt to fail it is possible that the severed pieces will foul the remaining two belts and destroy the drive. Even if the slippage does not cause failure it certainly is a source of power waste. In view of the facts that (1) prior to the SSP effort more than 3000 hours of running had been accumulated with a single o-ring driving a centrifuge (which is approximately ten times the running time accumulated on the 3-ring SSP drive) and (2) that the original single o-ring had been intentionally lacerated and nicked with a razor blade to accelerate failure, the RLSE unit was built with a single o-ring as the final element in the centrifuge drive.

3. Water production rates measured for the SSP version were not improved by the increase in centrifuge speed. It was concluded that the higher speed was penalizing because it required more power. For RLSE, therefore, the centrifuge speed was made to equal that of the pre-SSP machines. During RLSE testing, production rates were not as high as expected. The probable cause was traced to a characteristic common to both the RLSE and the SSP versions. That cause, preferential purge gas flow around the condenser rather than through it, is so significant that it may have obscured the gain earned by higher centrifuge speed (and power). There is evidence that the higher speed did improve boiler-side heat transfer coefficient because the SSP version production rate is very near that achieved with the RLSE unit, which was built with increased boiler surface area and a tighter compressor. It can not be concluded that RLSE centrifuge speed is optimum, or that investing in greater centrifuge power pays dividends in lower specific energy.

4. The external drive motor magnetically coupled to the still did achieve the goal of making the motor easily accessible, and successful operation was achieved. Problems with unbalanced windings, and loss of magnet effectiveness required that a better solution be found.

5. The selected speed sensor generated usable signals and provided a continuous reading of still operating speed. After testing, the still was placed in storage for approximately one year - apparently with some water present in the condenser. When the still was restarted it was discovered that the speed sensor was destroyed by internal corrosion. When the manufacturer could not explain the failures it was elected to locate the sensor in a well thereby keeping the sensor in cabin ambient. So arranged the sensor is protected from the still environment, no feed-through wiring is necessary, and the sensor, like the motor, is accessible for in-flight replacement.

   Boiler temperature was measured on the SSP version by a thermocouple located in the stationary shaft. The thermocouples, exposed to the same one year storage in the same saturated atmosphere, experienced similar failure by corrosion. For RLSE, the thermocouple was replaced with two precision thermistors located away from the central shaft giving a more accurate measure of boiler vapor space temperature.

6. The all stainless stills are very heavy, which is the major cause of long starting transients. When a thorough weight-reduction program is undertaken, and materials are less arbitrarily selected, shorter starting transients will result.

Discussed below are modifications made to the RLSE design which have no specific reference to the SSP version. In most cases these changes were made to correct deficiencies in most or all of the previous-built machines.

With all distillation units built between 1969 and the RLSE version axial location of the centrifuge was established by the bearing at the hub end opposite the compressor. The bearing at the compressor end constrained the centrifuge radially, but permitted axial motion to accommodate machining variations and thermal-related dimensional changes. The assembly sequence was such that the centrifuge bearing opposite the compressor is the last of the two to be installed, and when it was installed there remained no access to the boiler volume. The recycle impact tube often was in the wrong axial location relative to the boiler trench, and could not be reached without disassembling the last bearing - which, of course, removed the axial-location reference to the boiler. Assembly was, at best, a trial and error operation.

One obvious design correction was to cut large holes in the disk supporting the final bearing - to provide access to the impact tube with the bearing in place; afterward, the holes could have been covered by a second disk, but that would generate crevices in the boiler where biological activity could flourish. A better solution was to establish centrifuge location axially at the compressor-end bearing and let the opposite-end bearing accommodate tolerances and thermal expansions. Another advantage to this solution is that fewer tolerances can accumulate to cause an offset in the o-ring drive plane. In the RLSE machine impact tube location can be adjusted while the centrifuge is in its final axial location.

In previous machines the centrifuge bearings were located in the structure common to the condenser and the boiler - thus the compressor head rise was a pplied across the bearings. Commercial bearing seals were effective in reducing vapor flow through the bearings but the residual flow flushed the lubricant from the bearings exposing them to corrosion, particularly after long term static storage. To correct the deficiency, LMSC isolated the necessary functions of a low-friction dynamic interface and a vapor seal, and designed parts to perform each function well rather than trying to meet both simultaneously. The residual vapor flow which was causing lubricant loss was diverted around the active bearing by creating a preferential flow path. Downstream from the juncture of these flow paths is located a bearing (with balls removed) providing a carrier for the lip seal. All residual vapor flow must pass through this seal. Vapor flow through the active bearing was reduced to nil, and lubricant washout has been stopped. Testing of the VCD has confirmed this conclusion.

Maintaining compressor timing gear lubrication is difficult because in a zero-g application recirculated lubrication schemes (oil bath, or splash systems) are not usable and in this rarefied atmosphere application gear cooling by convection is reduced to an extremely low rate. Additionally, the surface speed and frequency of tooth engagement are high. The best solution to date has been to add high viscoscity lubricant (grease) to the teeth at regular intervals. In previous machines that was accomplished manually by partially disassembling the machine. For RLSE a grease reservoir was designed which can be activated by turning a screw located on the outer surface of the front plate adjacent to the motor. A pressure balancing port insures the lubricant piston is unaffected by normal pressure variations within the still.

Since the first use of impact (pitot) tubes it has been suspected that a turbulent zone was being generated in their wake, and that some recycle aerosol might have been cast into the vapor stream. Plans to visually observe the wake characteristics were dropped due to high development risks and costs involved. For the RLSE it was elected to place a stationary partition separating the recycle trench volume from the main part of the boiler (see Figure 3-19). The partition, or shield effectively isolates the trench zone from the main volume of the boiler. Should any mist be generated, it will be returned centrifugally back to the trench by the rotating parts adjacent to the shield.

Two significant improvements were made to the compressor built for the RLSE design. First, the rotors were electroless nickel plated to provide protection against corrosion. Second, and more significant, the lightening holes cast into the rotors were plugged at one end. As can be seen in Figure 3-20 these holes sweep past the vapor inlet hole, located in the end plate below the rotors, and nearer the bottom of the picture; they also sweep past the relief valve hole, located in the same plate adjacent to the rectangular discharge hole in the housing, near the top of the picture. The chamber formed by the rotors and open to the discharge hole is at high (exhaust) pressure. Similarly, the chamber opposite that and open to the inlet hole is at low (intake) pressure. It can be seen that exhaust pressure can be applied through the relief valve hole to fill the rotor lightening hole, and in the next quarter revolution that hole will be open to the inlet port. During every revolution of the compressor each of the four lightening holes dump high pressure vapor back to the inlet. The holes are 22.2 mm (0.875 inch)

- 2

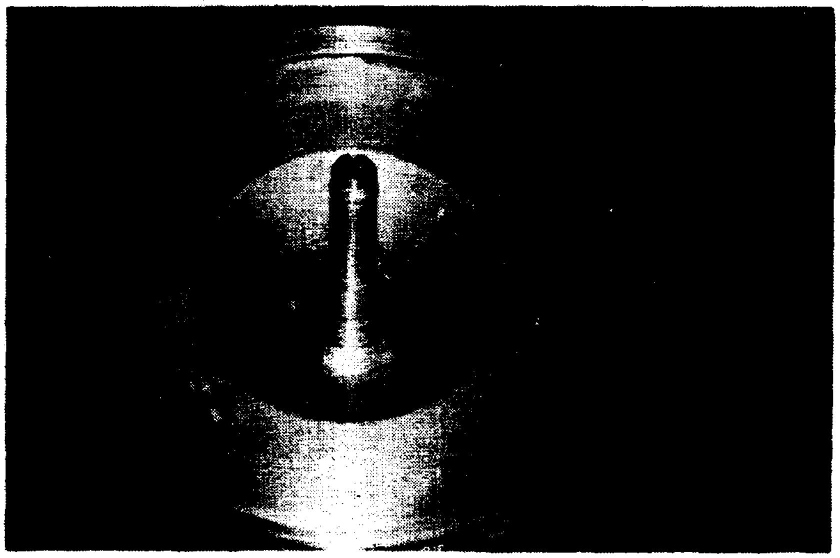


Figure 3-19 Recycle Trench Splash Shield

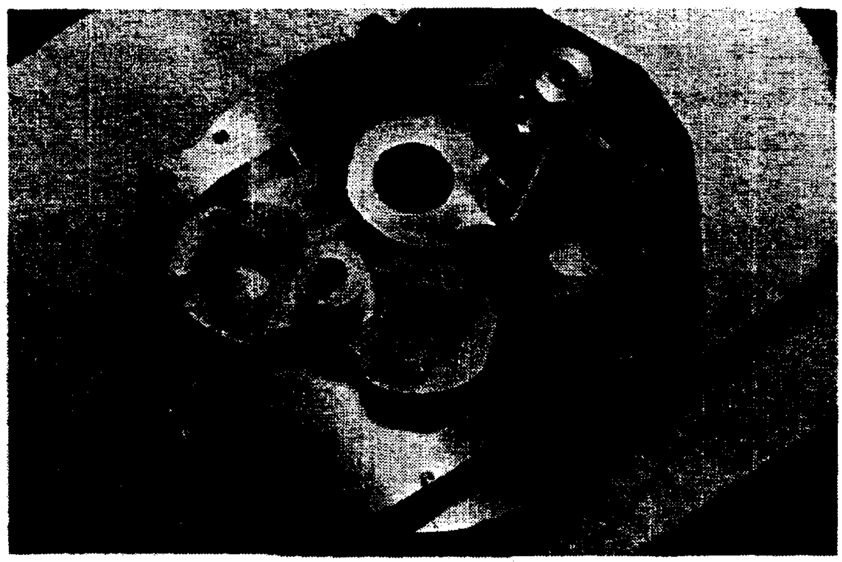


Figure 3-20 Compressor with Motor End Cover Removed

diameter and are 43.9 mm (1.73 inch) long. The displacement lost, assuming the holes are fully pressurized to exhaust conditions at one extreme, and fully exhausted to inlet conditions at the other is

$$\frac{(.875)^2 \pi \times}{4} \frac{1.73 \times 4}{1728} = 68.2 \mu m^3 \quad (0.00241 \text{ ft}^3) \text{ per revolution}$$

The "forward" displacement of the compressor is $402 \mu m^3$ (0.0142 ft^3) per revolution thus the back flow caused by vapor transfer via the holes is

$$\frac{0.00241}{0.0142} \times 100 = 17 \text{ percent}$$

Considering that the loss is subtracted from the productive speed (running speed minus slip speed). The actual loss is significantly greater than 17 percent. Back flow through the lightening holes was prevented by insertion of light gage stainless steel disks located at the ends of the rotors adjacent to the end plate shown in Figure 3-20 . One of the modified rotors is shown in Figure 3-21.

Frequently during earlier testing it was postulated that the relief valve had opened or was leaking compressed vapor back to the boiler. The function of the relief valve is to prevent an excessively high head rise from overloading the motor. Considering that an advanced monitoring and control circuit included a shutdown routine should high ΔP occur it was decided to hold the relief valve closed.

Severe corrosion occurred at certain locations in the SSP boiler after it was stored for an extended period. The most probable cause of that corrosion is that spot welding was applied to jig some of the parts together prior to a nicrobrazing operation, and the parts were inadequately cleaned in preparation for that operation. No corrosion was evident at joints formed either by nicrobrazing alone or by heliarc welding alone. Of those two processes heliarc welding is least susceptible to corrosion because no dissimilar metals are introduced. Heliarc welding was used exclusively for all RLSE boiler joining.

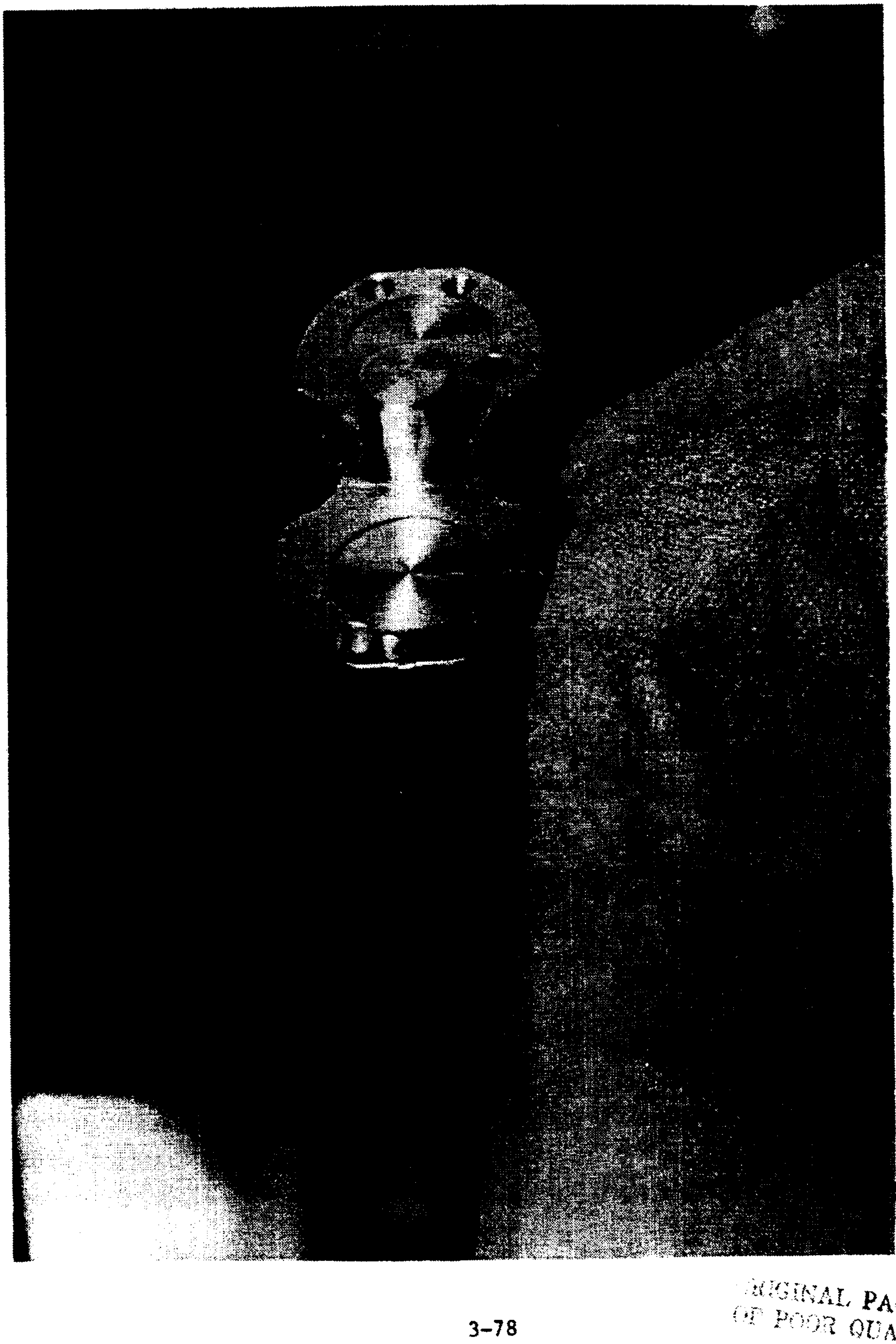


Figure 3-21 Compressor Rotor with Plugged Lightening Holes

During familiarization testing it was discovered that the SSP boiler was out-of-round by a significant amount. The cause of that irregularity has not been positively identified, but the SSP boiler, like all previous boilers was built without taking a final truing machine cut on the boiler surface to assure circularity and concentricity with the bearing surfaces. For RLSE that final cut was made. The boiler shell was made of slightly heavier than required material, then welded to the parts which were to become bearing surfaces. With appropriate tooling, the bearing surfaces and boiler surface were all turned in the same machine setup thus insuring concentricity and cylindricity.

The assembled distillation unit is shown in Figure 3-22.

First attempts to operate the still indicated stiffness and high mechanical drag. Assuming that this was a normal condition resulting from extensive rework, refurbishment, and relubrication, the still was operated with a 373W variable speed motor to "break it in". When the drag persisted a program for determining the source was started. Several obvious corrections were made. The centrifuge bearing cartridge seals were replaced with a more compliant variety. A loose key on the compressor idler timing gear shaft was located, corrected, and the compressor re-timed. A rubbing condition in the motor end bearing cartridge was corrected. Shims were inserted between the compressor central body and the centrifuge end side plate to alleviate lobe rubbing. Excess lubricant was removed from the lobes in the compressor.

Despite these corrections, the mechanical load was still too great. Three reasons could account for the drag: 1) lubricant too viscous, 2) stainless bearings too tight, or 3) moving parts not fitting together smoothly.

To determine if lubricant or bearings were the problem, one lobe of the compressor and its associated timing gear were removed. The centrifuge and its drive belt was removed. The power to turn the remaining lobe at ambient conditions was 123 W at 3750 RPM. This did not seem excessive, so the compressor was reassembled, and a tight spot in the timing gear mesh found.

The electroless nickel coating, which had been applied for corrosion protection, was stripped from one of the compressor timing gears. Discerning rubbing between the hermetic sleeve and the inner rotating magnet under vacuum conditions, the inner rotating magnet radius was ground down 0.254 mm (0.010 in.). Instead of the power decreasing, it increased. No satisfactory explanation for this increase was put forward except that the compressor assembly/disassembly procedure is not always repeatable. Changing the bearing lubricant from perfluoroalkyl polyether grease to Unitemp 500 produced a dramatic power reduction. Changing from stainless to alloy steel bearings was not a clear advancement, so the stainless bearings were returned. Concluding that the bearing and lubricant decisions were correct, attention was devoted to removing all vestiges of rubbing of moving parts. The electroless nickel coating was stripped from the second compressor timing gear. The compressor lobes were lapped in with lapping compound. Several attempts at retiming the compressor were made. With each measure, power was reduced.

Finally, the intermediate reduction shaft, centrifuge, and all drive belts were installed. All bearings were stainless steel lubricated with Unitemp 500 grease. The demister to central shaft clearance was increased. A final dry vacuum power consumption of 78W was achieved, and the still placed in service. Two findings result from this effort. First, a roots blower is a statically indeterminant mechanism. The lobes are essentially two-toothed gears meshing under control of a remote set of timing gears. The timing gears must dominate, and the lobes be subordinate. The lobes must include enough clearance to compensate for manufacturing and assembly errors. If not, clashing occurs. As clearance increases, so does slip, and performance declines. Secondly, when dealing with low power systems, the slightest amount of additional drag can consume considerable fractions of available power.

When first operating the still, compressor performance did not seem to be up to par. Regular drydown was not achieved, and even after condensate was manually extracted, the compressor delta pressure rise was weak.

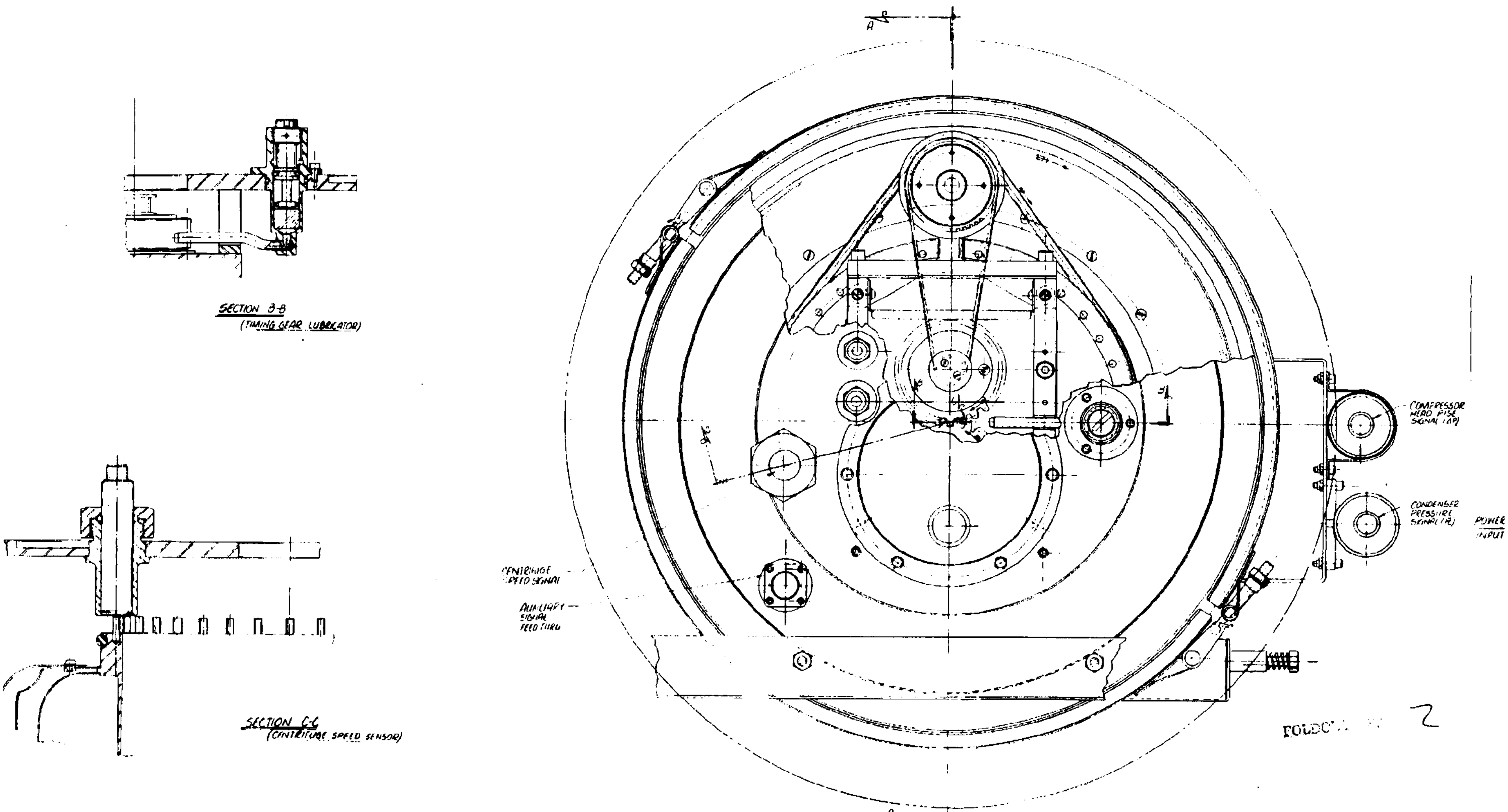


Figure 3-22 RLSE VCD Distillation Unit Assembly

FOLDOUT FRAME

FOLDOUT 2

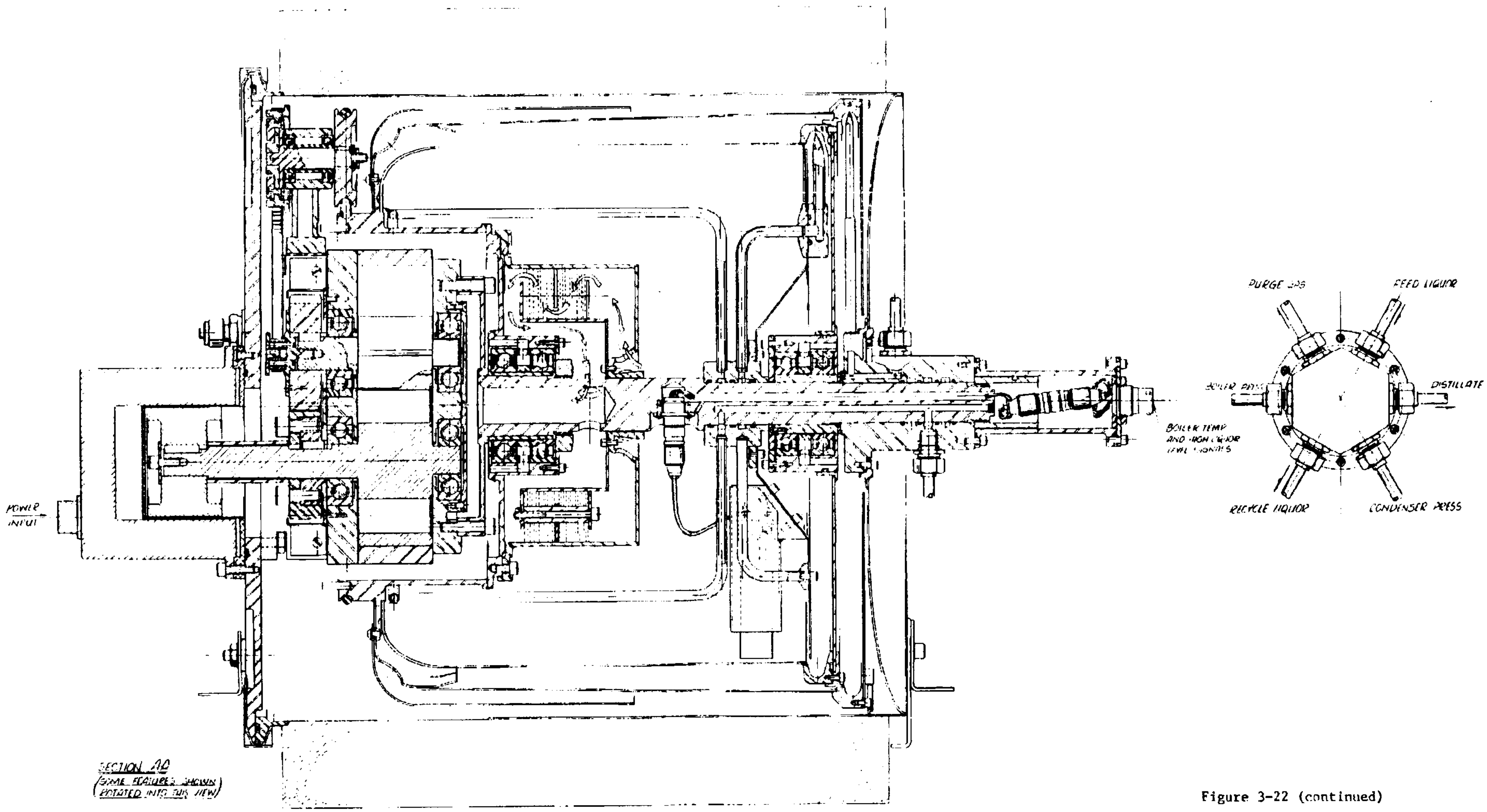


Figure 3-22 (continued)

Since leakage was suspected, a system characteristic curve was developed plotting compressor delta pressure versus condenser pressure for known dry still conditions. The results are shown in Figure 3-23 and indicate a weak system which could never attain 2 kNm^{-2} (15 mmHg) shut down pressure unless the condenser was at 4.7 kNm^{-2} (35 torr). The still was opened and checked for leakage paths. None were found. A compressor characteristic curve was developed by removing the entire centrifuge and blocking the compressor inlet. This produced the much improved curve shown on Figure 3-24. Something in the system was defeating compressor performance. The only thing left was to reverse the position of the rotating bearing lip seal. This seal was installed on the downstream side of the bearing to preclude drag augmentation under pressure. However, it was lifting and allowing too much backflow to occur. Upon reversal, the system characteristic curve was plotted and as shown in Figure 3-24 very nearly approaches that of the compressor alone. Although the system performance was improved, no successful normal drydowns were ever achieved. Characteristically, recycle flow would fall off to zero within a few minutes and from then on, the diverted condensate would cycle through the boiler/condenser via the reprocess loop with no sign of compressor delta pressure ever reaching shut-off level. The assembled, and installed distillation unit is shown in Figure 3-25.

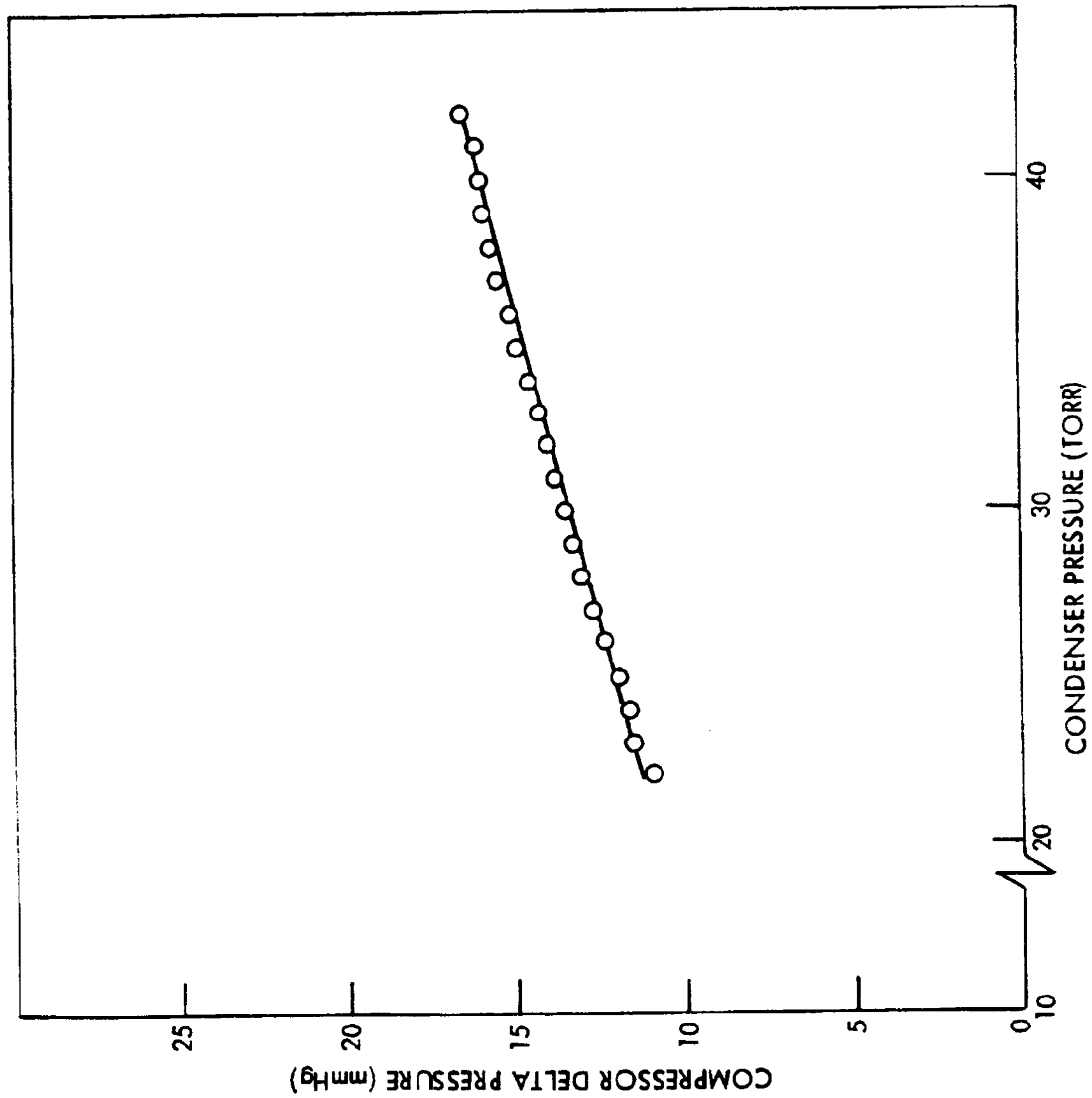


Figure 3-23 Initial Compressor Characteristic Curve

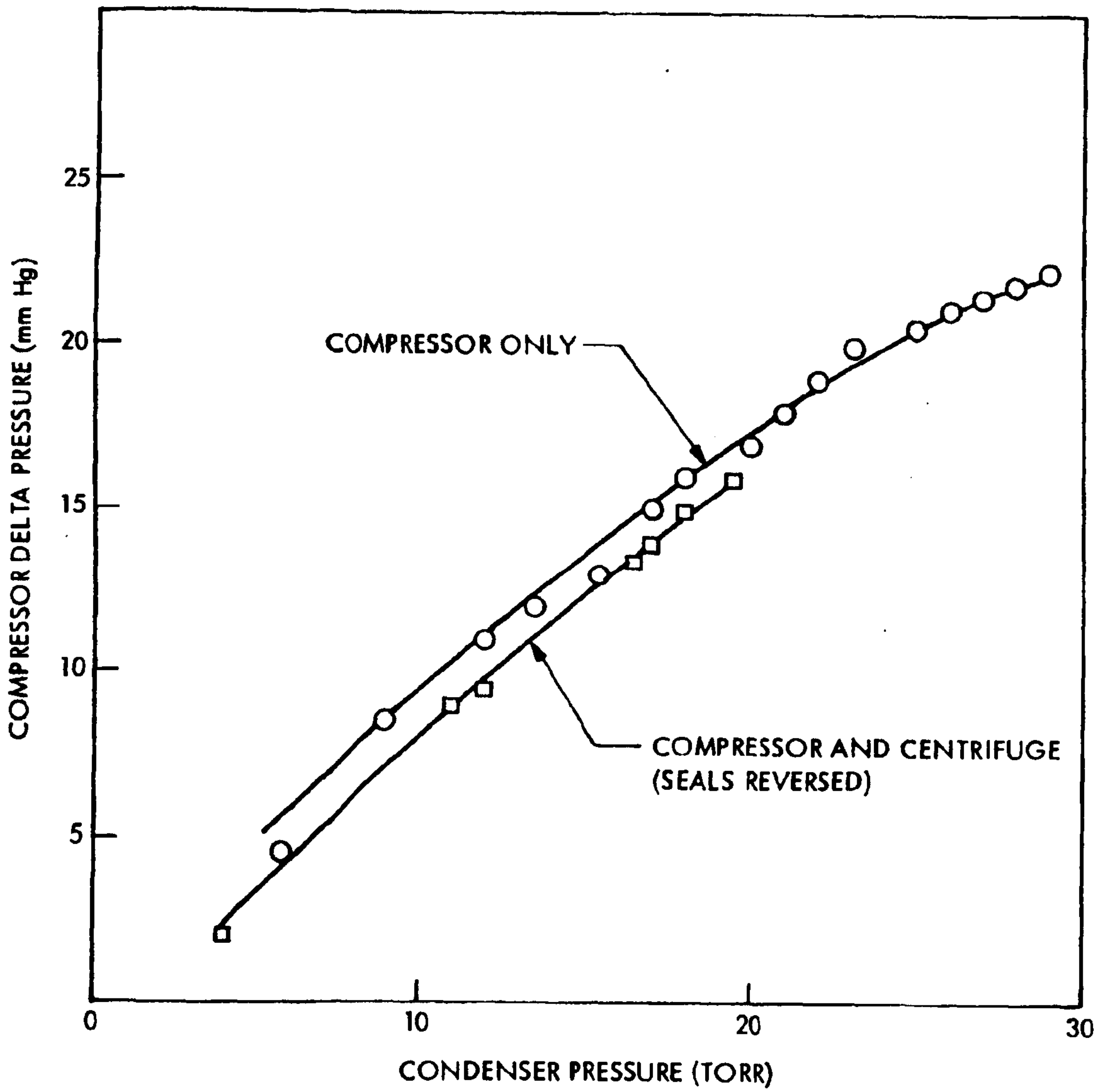


Figure 3- 24 Final Compressor Characteristic Curve

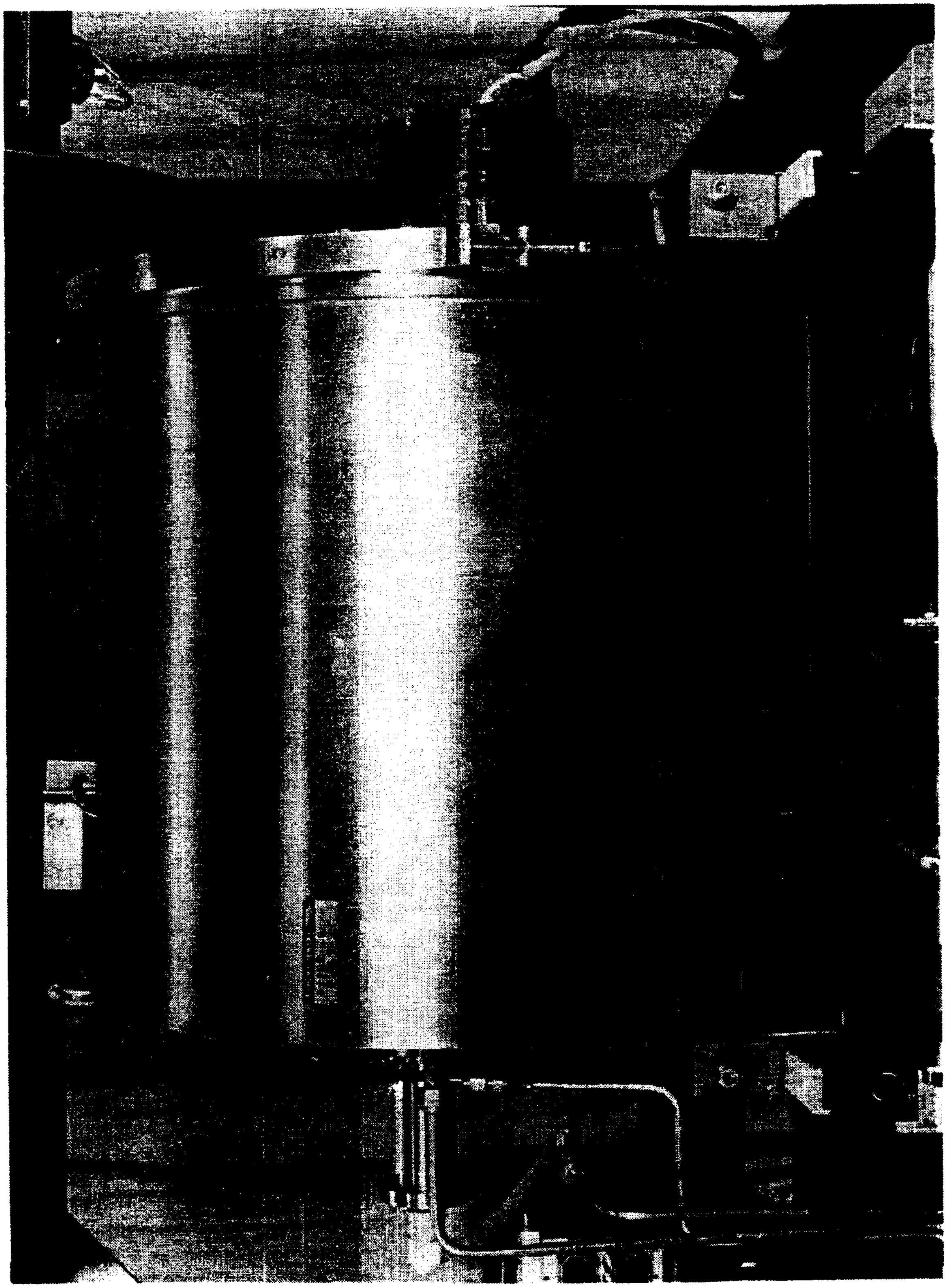


Figure 3-25 Installed Vapor Compression Distillation Unit

3.8 Lubrication Development

Through successive development contracts Texaco Unitemp 500 grease has been selected as the preferred lubricant for compressor, centrifuge, and intermediate shaft bearings. It possessed the qualities of good lubricity and non-toxicity while maintaining fair washout and corrosion resistance. Unfortunately it also was characterized by its blue color and its tenacious ability to stain clothing and skin.

To improve the washout and corrosion resistance, a survey of current state of-the-art lubricant systems was undertaken. Three candidates were obtained and tested. The principle ingredient of these systems is a greaseplate formulated to inhibit the corrosion of non-load bearing surfaces. A common failure mode of unprotected bearings is the introduction of corrosion induced particles from the outer surfaces of the bearing into the balls and raceways. By definition, greaseplate is a thin coating of high consistency grease which is made possible by applying the grease in solution form.

A grease is an oil modified by the addition of a thickener. Most greases use a metallic soap as a thickener, but these have a high wash out rate, therefore a low molecular weight polytetrafluoroethylene thickener inert to chemicals, water, and solvents was chosen. The oils chosen were fluorosilicones, synthetic hydrocarbons, and perfluoroalkyl polyethers. A greaseplate consisting of high viscosity perfluoralkyl polyether oil, thickened with polytetrafluoroethylene was used. This formulation was mixed with freon propellants and sprayed from an aerosol container.

A test setup shown in Figure 3-26 and 3-27 was operated for 30 days round the clock. An air motor was rigged up to rotate the inner races of 12 ball bearings mounted on a single shaft. The outer races of the bearings were restrained by clamps fastened to a support structure. The lower 6 ball bearings were immersed in pretreated urine contained in a beaker. The whole apparatus was enclosed within an evacuated bell jar. The urine was heated so that the inner atmosphere of the bell jar was always in a state of

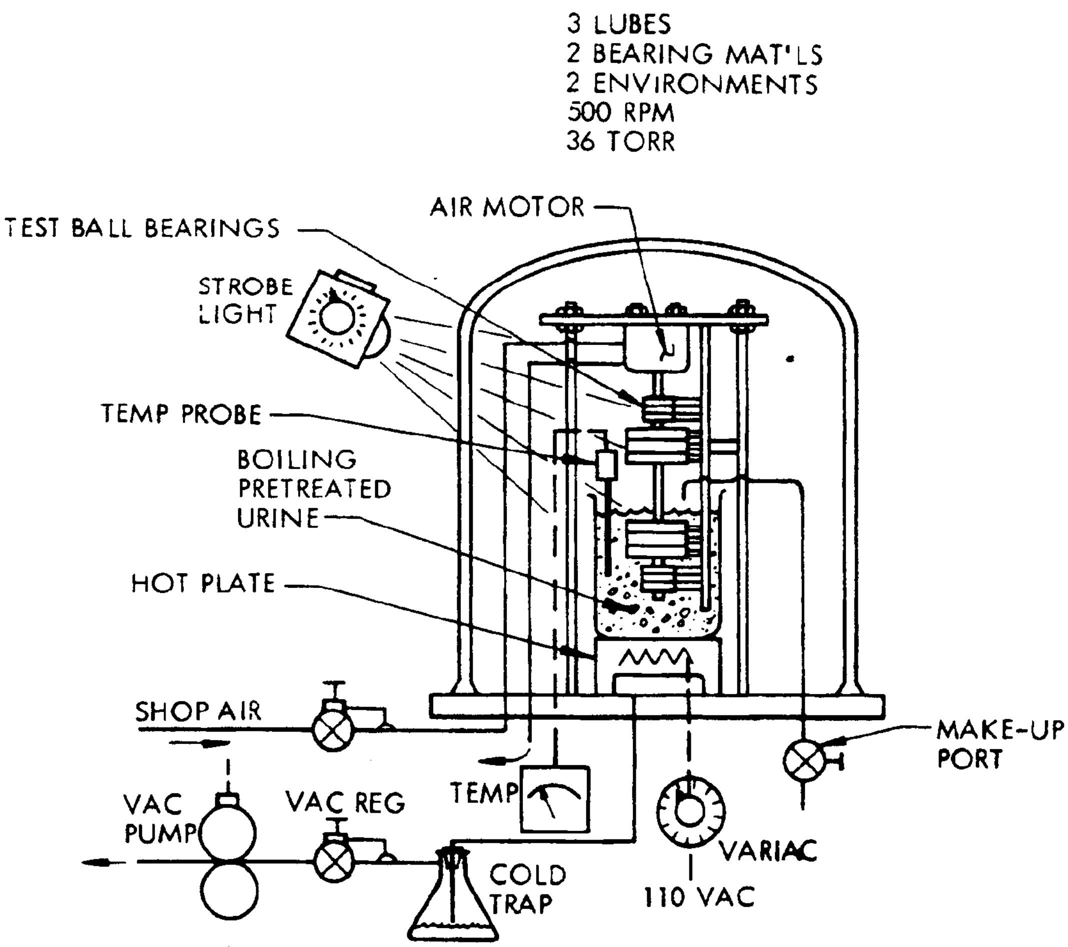


Figure 3-26 Components of Test Apparatus

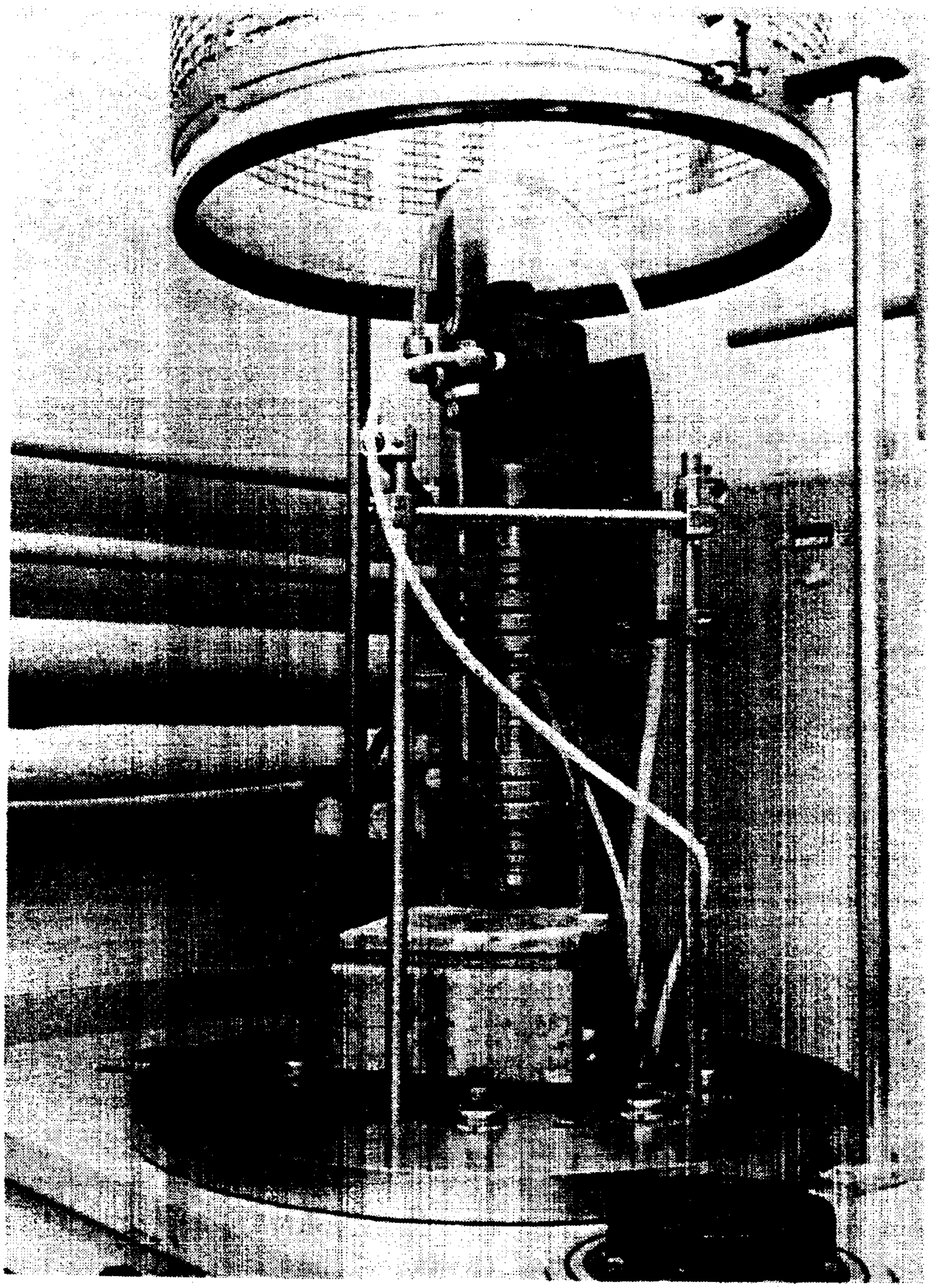


Figure 3-27 Photograph of Shaft Assembly

saturation. Inasmuch as possible, VCD conditions were simulated. Two sizes of bearings, two bearing materials, two environments, and three lubricant systems were tested By monitoring speed and air pressure, torque changes could be noted.

At the termination of the test, all bearings were capable of free rotation. All the AISI 440C bearings were in excellent condition and showed little wear. The SAE 52100 bearings also showed excellent condition with little wear.

The test results indicate that a greaseplate is capable of protecting lubricated alloy steel bearings in a hostile water environment. Any good lubricating grease with minimal water washout properties can be applied to the load bearing balls and raceways. The selection of the perfluoroalkyl polyether oil thickened with a tetrafluoroethylene low molecular weight polymer is optimum. The final effect is one of covering the vulnerable components of the mechanism in a soft, inert blanket of Teflon by means of an uncomplicated spray application to provide the protection required.

As mentioned in the discussion in Vapor Compression Still developments, the selected grease was abandoned because of viscosity reasons. However, the greaseplate was retained for its resistance to corrosion in non-load bearing areas.

3.9 Instrumentation Development

Several sensors were either developed, or upgraded during the early phases of the program. Details of these developments are presented below.

3.9.1 pH Sensor Development. The SSP unit had a problem with control of recycle loop acidity. Being sensitive to this problem during familiarization testing at LMSC, numerous samples of recycle fluid were monitored for acidity. The pH ranged between 2.75 and 3.0.

At a pH of 4 or higher, loss of bacterial control is a real possibility. Recovery from high pH can be effected by acid additions if accomplished soon enough i.e., within 24 hours. The decision was made to install a pH sensor in the recycle loop which would continuously monitor pH but only display the fact that a pH of 4 or greater had been attained.

Conventional laboratory pH sensors utilize two electrodes one of which is a reference and the other a measuring electrode. The reference electrode is filled with an electrically conductive fluid which communicates with the aqueous media through a porous member. It is the scaling or fouling of the reference electrode which causes failure. Maintenance of electrolyte flow has been accomplished by use of mechanical scrubbers, ultrasonic transducers, osmotic diffusers, and flowing junctions.

An in line pH electrode designed for direct installation in a pipe line for continuous monitoring was purchased (Model 9037 Presto-Tek Corp., Los Angeles, California). This sensor utilizes the diffusion concept of reference electrode. It features both the pH and reference junctions constructed in a single stem for one-probe convenience. The sealed reference needs no pressurization or filling during entire probe life. The combination pH electrode is potted permanently into the PVC housing with a 3/4 inch NPT fitting. Dimensions are 25.4 mm (1.0 in) diameter by 152.4 mm (6.0 in) long. The pH range is 0-14, temperature range 5-80^{o}C (41-176^{o}F), and pressure range 0-689 kNm^{-2} (0-100 psi).

A 6 month endurance test of this sensor was conducted by immersing it continuously in a stirred beaker of pretreated urine/flush water. As the urine/flush water evaporated, makeup was added. No attempt was made to clean the electrode. Periodically the pH was read, percent solids taken, and response to radically differing buffer solutions noted. The pretreated urine/flush water pH varied between 2.8 and 3.5. At test end, the solids were measured at 42.5%. Response of the sensor to varying buffer solutions was both accurate and immediate. The sensor is mounted in the VCD recycle loop and has functioned satisfactorily throughout all testing.

The installed sensor is shown in Figure 3-28. The sensor is identified as component number 41. Recycle liquor flow enters from the lower right into the end of the sensor and exits upward from the side of the sensor into the Hamilton Std. check valve.

3.9.2 Centrifuge Speed Sensor Development. The SSP centrifuge speed sensor was inadequate due to a very low signal strength and corrosion. The low signal strength of the passive SSP magnetic sensor required a very close clearance dimension, 0.13 mm (0.005 in), between the stationary sensor and magnetic material. Rubbing would frequently occur. Due to this close proximity requirement, the sensor was located inside the still. Some of the materials were corrodable, and eventually rusted. Both problems were overcome by the RLSE design.

A new magnetic pickup was procured (Model LMP-OC Red Lion Controls, York, Pa.17402) which incorporates a built in high gain preamplifier. Internal filtering reduces sensitivity 6 db/Octave which compensates for the natural rise in pickup voltage and gives a very high EMI rejection. The overall result is a sensor which is extremely sensitive at low surface speeds, and large air gaps, has excellent noise immunity, and good high frequency response.

Taking advantage of the large air gap capability, a well was constructed in the still end plate. A series of 36 magnetic pins were installed in the end of the centrifuge to pass close to this well and provide the necessary pulsing of the pickup. With the sensor now located outside the still, corrosion problems, replacement problems, and electrical penetrations were overcome.

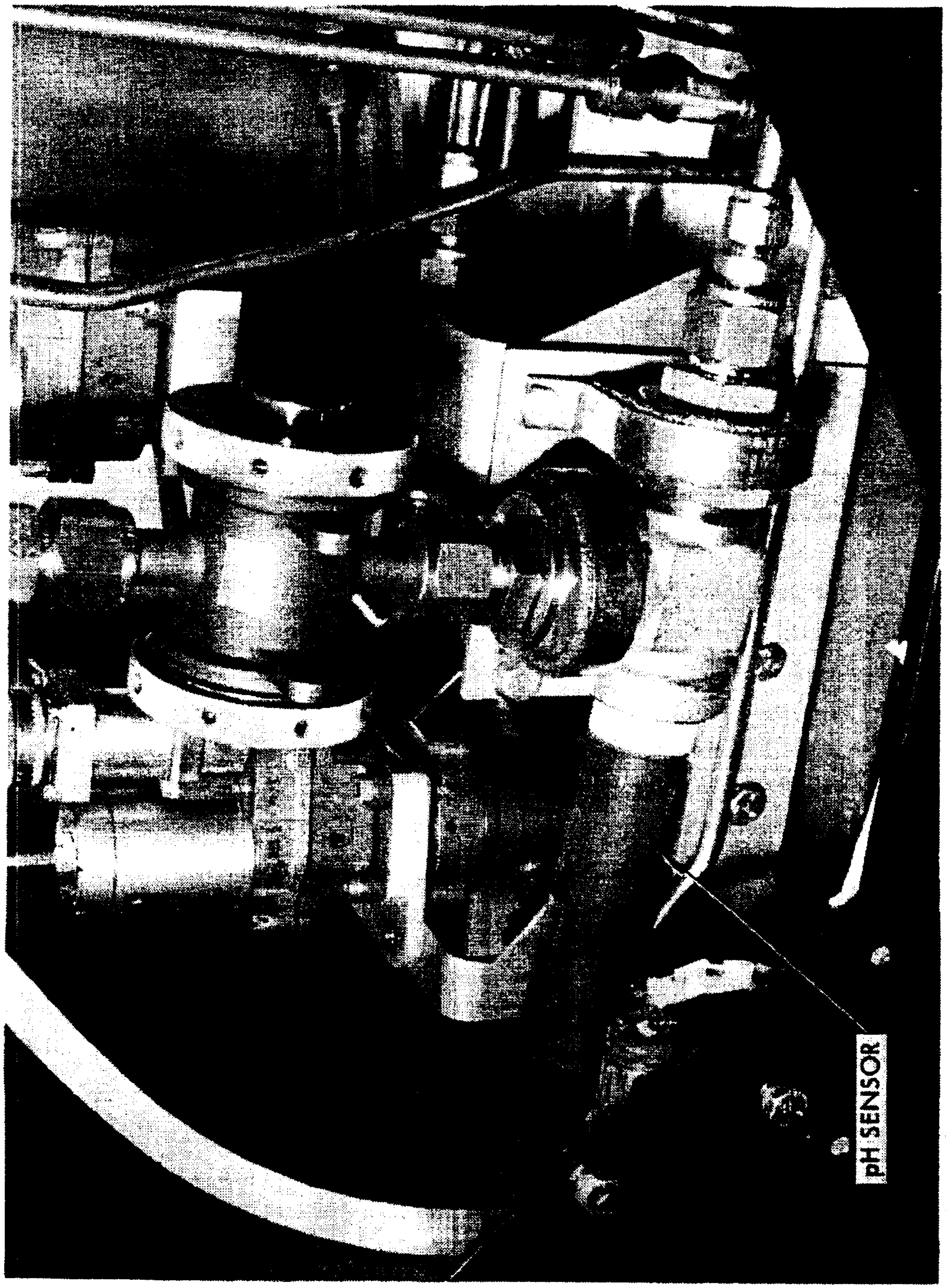


Figure 3-28 Recycle pH Sensor Installation

3.9.3 Liquid Level Sensor and Evaporator Temperature Sensors Development. The liquid level sensor is a stainless steel paddle which is deflected when the liquid level in the boiler rises excessively. At a narrowed down section, two strain gages (Type SP B3-20-35, BLH Electronics, Inc. Waltham, Mass. 02154) are applied, one in tension and the other in compression. These two gages form one half of a bridge circuit. The remaining half is located in the controller. When a bridge imbalance occurs, a display lamp lights, and after 5 seconds continuous imbalance, the controller commands DRYDOWN. Since both gages exist in the same environment, they provide automatic temperature compensation to the circuit.

The strain level and wake chacteristics were studied with a simple flooded inclined trough development test rig. A wrap around guard protects against the majority of random splashes.

Bonded to the same paddle are two precision thermistors (Model UUA 33J4, Omega Engr. Inc., Stamford, Conn. 06907) used to sense evaporator temperature. The thermistors are isolated from the paddle by interposition of a small sheet of fiberglas. A transfer terminal strip (for terminating gage leads and conversion to Teflon insulation) was bonded near the strain gages. The base wires and terminal strip were coated with type "D" m-coat. Wire insulation was chemically etched. BLH barrier "E" was added for final waterproofing.

Either thermistor may be selected for both control or display by operating a three position switch on the controller. The third position removes both thermistors from the control/display circuitry in case manual override of a high temperature DIVERT is desired.

The bare sensor paddle and its final subassembled condition are shown in Figure 3-29. The narrowed down section where the strain gages were applied is inside the black waterproofed area shown in the assembly version. The sensor assembly is cantilever mounted on the boiler side of the recycle splash cone. A connector provides rapid removal during still disassembly.

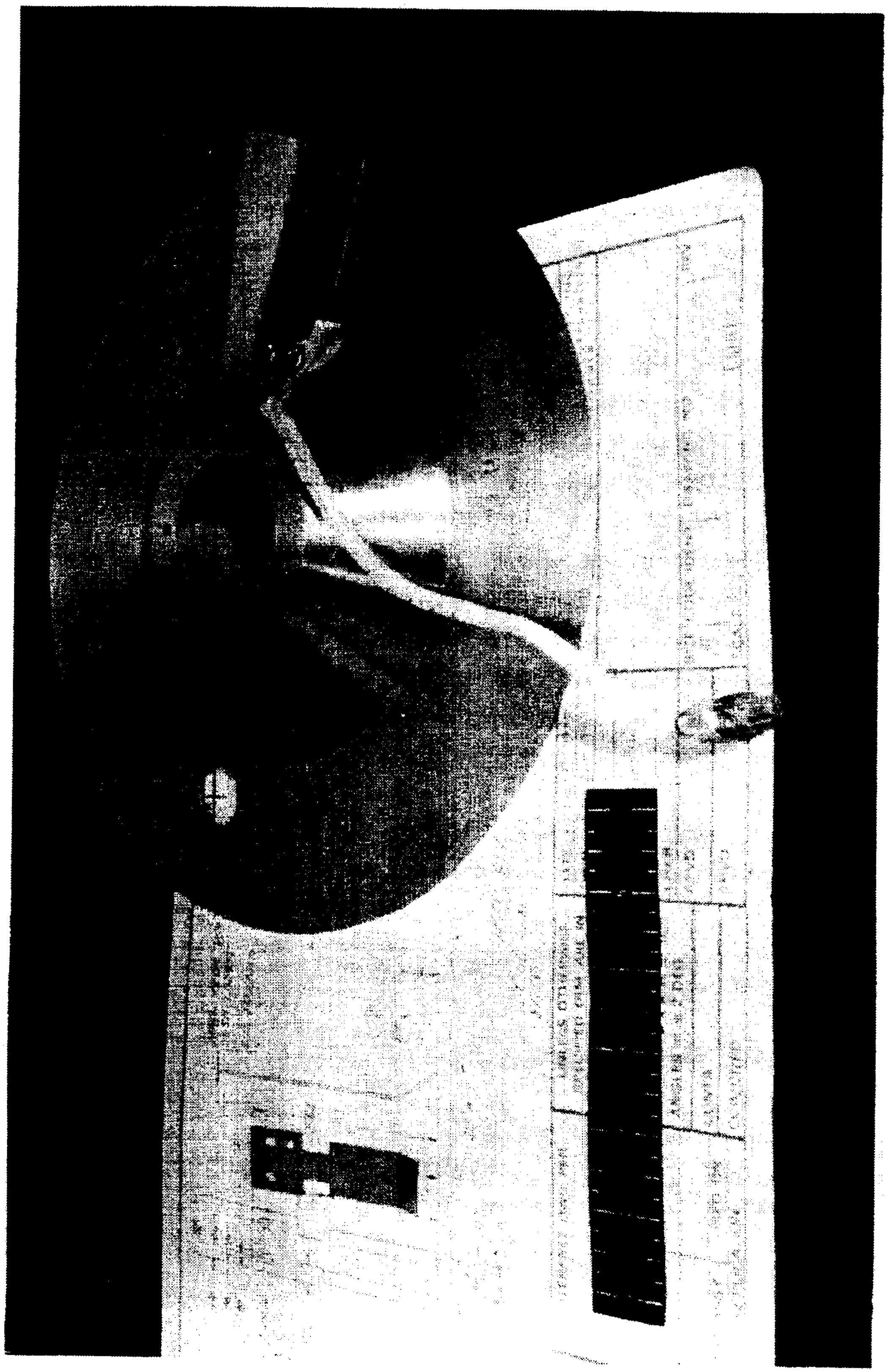


Figure 3-29 Liquid Level and Boiler Temperature Sensors

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3.9.4 Conductivity Sensor Development. Dissatisfaction with the conductivity sensor reliability resulted in two more sensors (Model 910-.1 TMSGE-1, Balsbaugh Lab. Inc., S. Hingham, Mass. 02043) being added in series. When expanding the excitation and monitoring circuitry to accommodate the new sensors, a wiring error was found which deprived the original sensor of approximately half its range. The error was corrected. No difficulties were noted thereafter.

3.10 Condensate Boost Pump Development

One of the first determinations of required instrumentation included some method of accurately measuring condensate production rate in zero-g. A number of concepts were explored but found inadequate when dealing with the low flow rate and limited delta pressure available for operation. One unit produced commercially for measuring gasoline flow in cars and trucks was tested. This meter utilizes the principle of a ball orbiting through a toroidal channel propelled by the flow of the fluid. The ball density is matched to fluid density. Each orbit of the ball interrupts a light beam and provides an output signal. Unfortunately, this meter was not positive enough and at very low flow rates the ball stopped orbiting.

A new requirement from RLSE required that VCD discharge condensate into a 206.8 kNm^{-2} (30 psig) receiver instead of the 34.5 kNm^{-2} gage (5 psig) previously planned. The action taken upon receipt of this requirement was to design a condensate boost pump which would serve the parallel function of condensate flow meter.

Design requirements established were:

Max. Pressure rise	241 kNm^{-2} (35 psi)
Flow quantity per cycle	50 μm^3 (50 cc)
Maximum inlet pressure	34.5 kNm^{-2} (5 psi)
Maximum Electrical Power	10W

The resultant design incorporates a commercial rolling diaphragm cylinder which accumulates condensate discharged from the peristaltic fluid pump. When the accumulator has acquired $50 \mu m^3$ (50 cc) of condensate, the push rod actuates a micro switch causing a gear motor to rotate a cam which returns the push rod to its original position. A second micro switch in parallel with the first maintains motor power on until the push rod reaches its original position. A third micro switch provides an indication to the display circuitry that $50 \mu m^3$ (50 cc) has been delivered. Check valves in the fluid line control the direction of liquid flow in and out of the cylinder. The cylinder was electroless nickel plated to inhibit corrosion. In case of diaphragm rupture, a drain line connects the cylinder case to a dump interface connection. The cylinder is spring-return loaded and requires from 10.3 to 14.5 kNm^{-2} gage (1.5 to 2.1 psig) to fill it. The check valves open at 6.9 kNm^{-2} (1 psi) therefore the input pressure must be at least 21.4 kNm^{-2} gage (3.1 psig) to fill the unit, and an outlet back pressure of 28.3 kNm^{-2} gage (4.1 psig) must be maintained to prevent flow through the checks.

The unit discharges in 8.5 sec. approximately every 2.5 min. and at that rate consumes an average of 4 W.

Section 4
SUBSYSTEM DEVELOPMENT

4.1 Subsystem Arrangement

The VCD subsystem is shown in Figures 4-1, 4-2, 4-3, and 4-4, a series showing all four sides. The frame was constructed of aluminum extrusions and castings joined mechanically with locking clips and riveted gussets at each joint.

The geometry of the frame was dictated by the current dimensions and experiment payload envelopes set forth for Spacelab Experiment Racks in the Spacelab Payload Accommodation Handbook SLP/2104. The nominal envelope of a double rack is 940 mm (37.00 in.) wide by 612 mm (24.09 in.) deep by 1490 mm (58.66 in.) high. The top and bottom rear corners of this volume are further reduced by triangular prism chamfers reserved for ducting, cabling, and other interfaces. The full height of 1490 mm was not required. However, it was elected to use the width, depth, and the trangular truncation dimensions as a packaging discipline for the subsystem. The frame members are 38.1 mm (1.5 in.) wide and provide reserve space, should it be needed, for prototype designs. The module theoretically should slip into an ESA rack as built. For future designs there may be merit in having a subsystem built into such a frame and mounted on slides for access in Spacelab. Nonetheless, all components were organized for servicing from the front only. The five major components (controller, still, liquids pump, waste tank, and recycle tank) are mounted on slides, have quick disconnect MDV valves, and electrical connections. With all five components removed, no difficulty exists in servicing any portion of the VCD from the front.

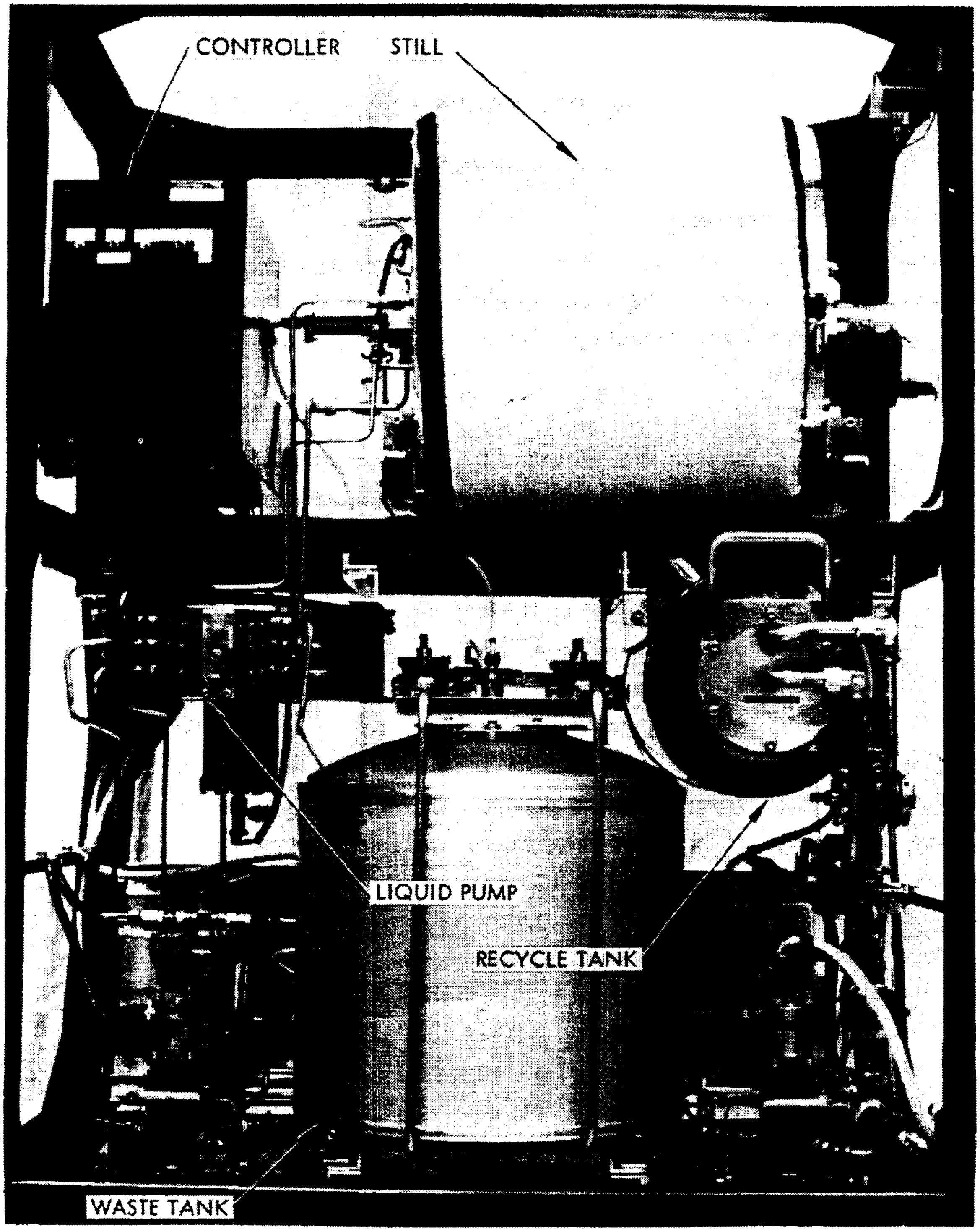

Figure 4-1 VCD Subsystem Front View

Figure 4-2 VCD Subsystem Left Side View

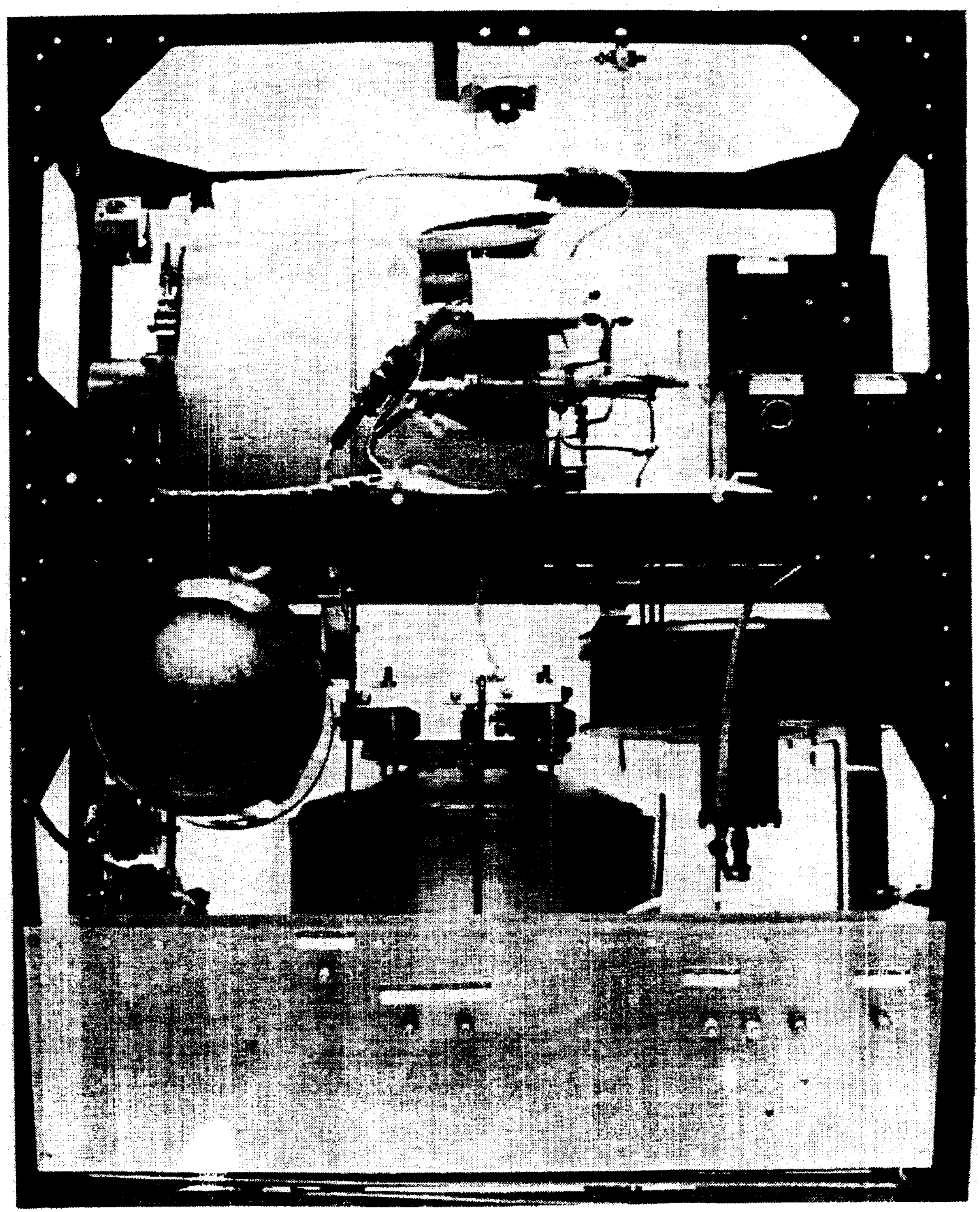

Figure 4-3 VCD Subsystem Rear View

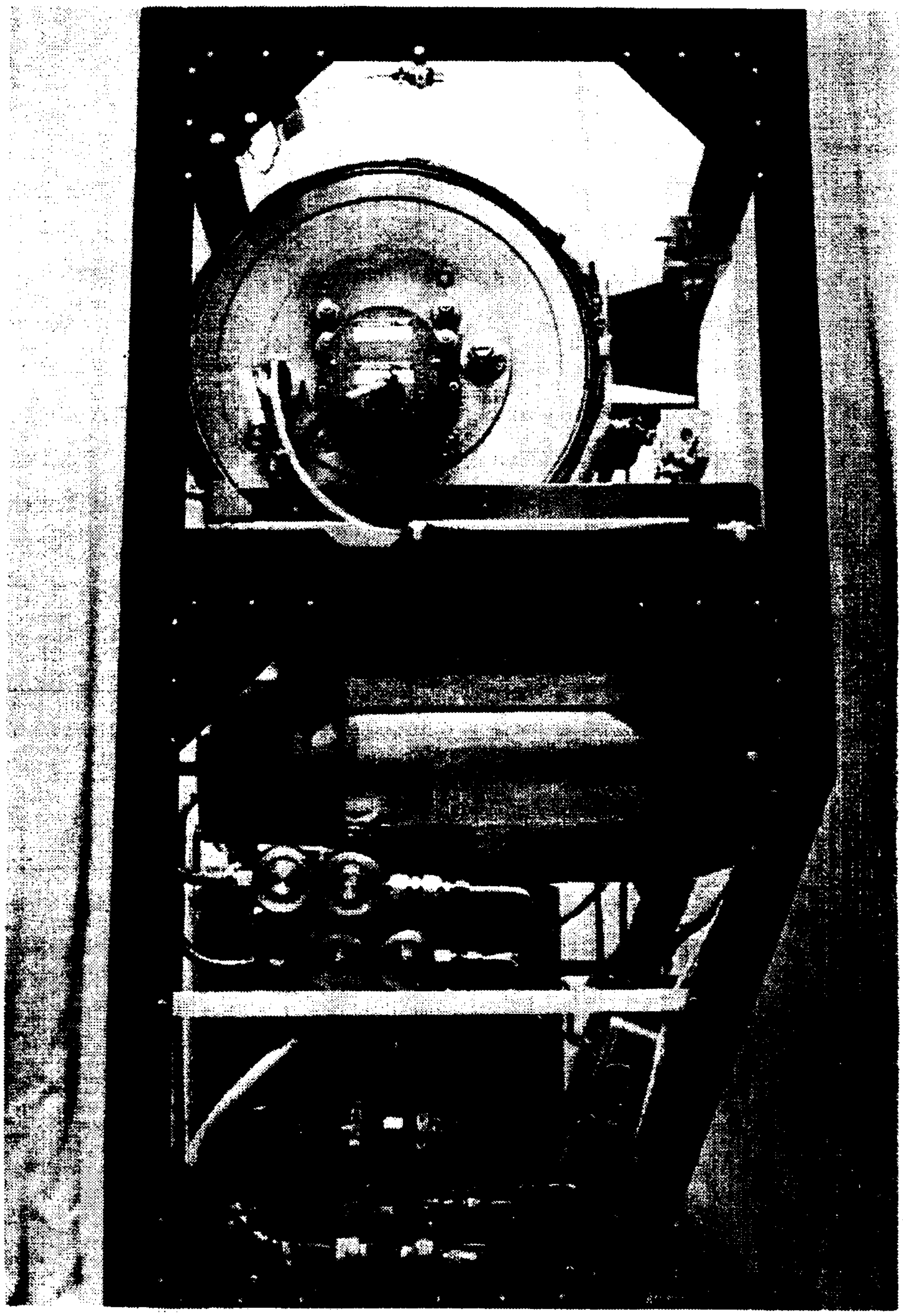

Figure 4-4 VCD Subsystem Right Side View

No attempt was made to standardize on one specific manufacture or style no electrical connectors if it significantly impacted cost. Similarly, different types of plumbing connections exist. In most cases, SWAGELOK AISI 316 stainless steel fittings were used.

4.2 Subsystem Interfaces and Operation

The VCD module schematic is shown in Figure 4-5. RLSE subsystem interface designations are used. RLSE has designated VCD as Urine Processing Subsystem 11. The electrical inputs are: 3 phase, 400 Hz, 208 V (line to line) alternating current, and 29.5 $\pm$ 2.5V direct current. Avionics cooling air is ducted in at interface 11G2-AV. Part, or all of the avionics air is returned at interface 11G1-AV. If some of the avionics air is distributed generally within the VCD it then exits the module designated as interface 11G7-CAB. No air inflow from cabin is foreseen. Small temporary fans were used at LMSC to serve the purpose of avionics cooling air. Gaseous nitrogen pressurant is input at interface 11G6-09. Pretreated wastes are received at 11L4-10 (urine) and 11L5-09 (hyperfiltration brine). These wastes are mixed indiscriminately in the module and enter the variable volume waste tank (C/N 7). The pressurant, regulated to 34.4 kNm^{-2} gage (5 psig) maintains fluid pressure between 20.7 - 41.4 kNm^{-2} gage (3-6 psig) depending on the displacement of the metal bellows from null position. The waste tank has two waste ports and by appropriate setting of a recycle flow direction valve (C/N 15) can function in either a flow-through or strictly makeup mode. Regardless of mode, makeup waste enters the process stream just upstream of the feed shutoff valve (C/N 21) and is "metered" into the vapor compression still (C/N 29) by the feed section of the liquids pump (C/N 25). The wastes are distributed inside the rotating boiler section where some of the water evaporates. The remainder overflows a dam which controls the thickness of the boiling fluid and is picked up by an impact tube leading to the recycle section of the same liquids pump. This recycling flow is routed through a pH sensor, set to alert the operator at pH greater than 4 and check valve

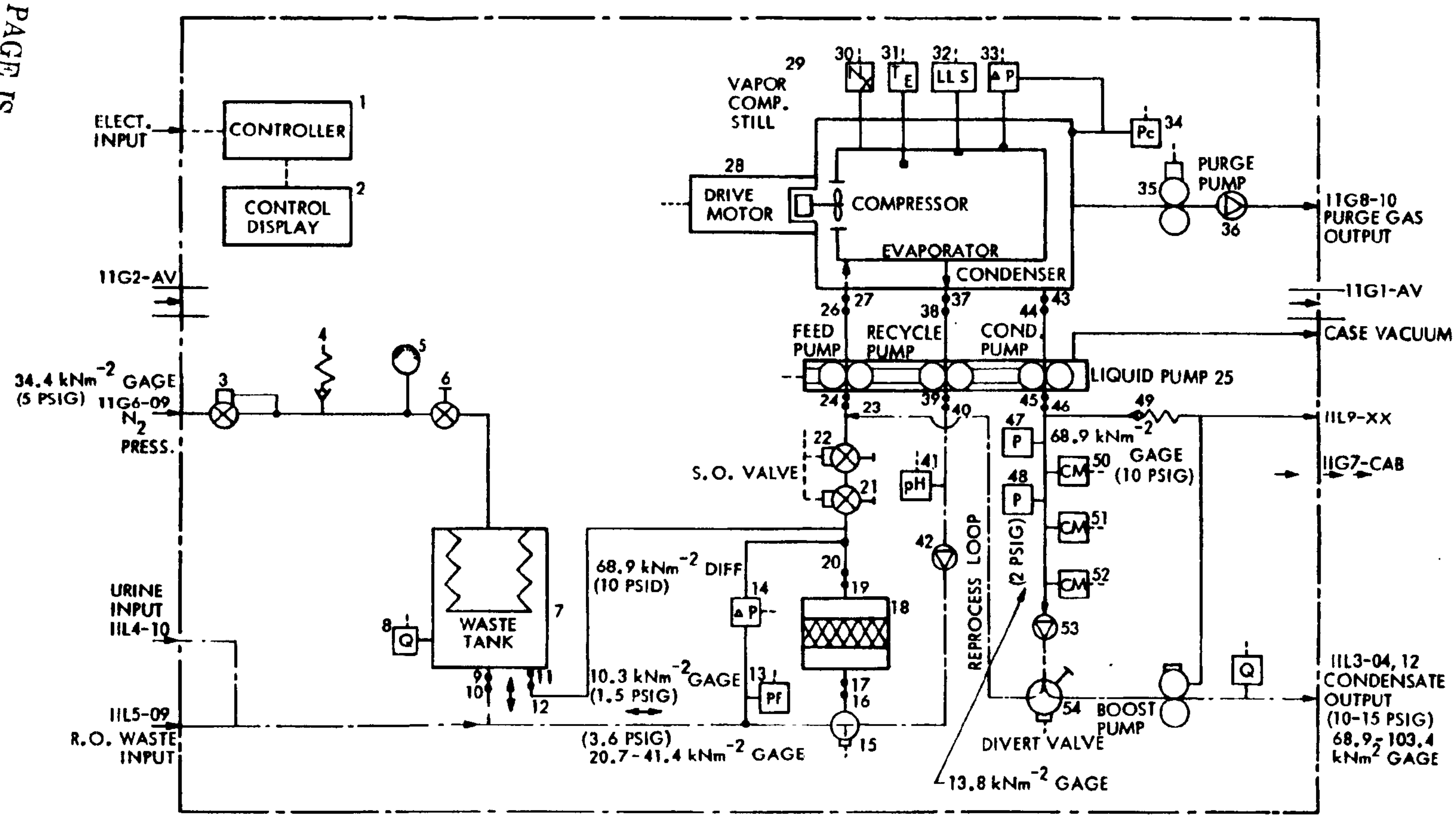

Figure 4-5 RLSE Vapor Compression Distillation (VCD) Module Schematic

(C/N 42) to either the waste tank or through the recycle tank (C/N 18) depending on the placement of the recycle flow direction valve.

Waste fluid pressure is sensed by a pressure switch (C/N 13) set at 10.3 kNm^{-2} gage (1.5 psig). If waste pressure becomes less than this value, the operator is alerted, and the VCD is switched to DRYDOWN. A differential pressure switch (C/N 14) is set to alert the operator that the recycle tank filter is clogging when 68.9 kNm^{-2} (10 psi) differential exists.

Maintenance disconnect valves (MDV) are represented by black dots (C/N 9, 10, 11, 12, 16 etc.) and are always installed as mating pairs. These valves permit fluid isolation when removing a component.

The portion of the waste water which is evaporated in the boiler is compressed and routed to the outer surface of the boiler. Now, possessing a favorable delta temperature, it condenses returning the latent heat through the thin common wall to assist in boiling "new" waste stock. After condensing, the water is collected and picked up by another impact tube leading to the condensate section of the liquids pump.

The condensate is monitored by three conductivity sensors (C/N 50, 51, 52) for a satisfactory low salinity (less than 40μmho cm^{-1}). Output pressure of the condensate pump is sensed by two pressure switches (C/N 47, 48) which alert the operator if a tube failure or blockage occurs.

The condensate passes through a check valve (C/N 53) and, depending on the placement of diverter valve (C/N 54), into a booster pump (C/N 55) where its pressure is raised and its volume measured and delivered to the next subsystem at interface position 11L3-04,12. A relief valve (C/N 49) protects the condensate pump in case of a blockage. Together with any outflow resulting from booster pump cylinder leakage, these streams are led to a fluid dump connection 11L9-XX.

In the event condensate conductivity is too high, the diverter valve is placed in the divert position. Condensate flow is then routed back to the feed pump inlet for reprocessing. When condensate conductivity returns to an acceptable value, the diverter valve is repositioned. As condensate leaves the subsystem, the waste tank makes up for the fluid loss. On a nominal daily basis, the waste tank eventually empties and the VCD shuts off. A purge pump (C/N 35) evacuates the still during STARTUP and continually removes non-condensibles while operating. Output from this pump exits the VCD at interface position 11G8-10. A port for application of vacuum to the liquids pump casing is provided at interface position 11G10-10. The entire concept of operation was designed for minimum operator attention. Upset conditions are either self-correcting, fail safe, or of such long time constants that continuous operator attendance is not required.

The salts in the feed stock are concentrated in the recycle tank. Eventually, the salts reach such a high percentage that further processing becomes uneconomical. At that point, a fresh recycle tank is exchanged for the concentrated one and the VCD returns to its initial production rate. Early in the program a new technique of VCD operation was proposed. This technique, designated "Low Solids" operation, takes advantage of the fact that the solids in the waste tank are always low, whereas the solids in the recycle stream eventually become very high (50% by weight) at the end of a nominal solids concentration cycle (30 days). If recycle flow were directed through the waste tank, then recycle flow solids on day 30, would be the same as on day one. In actuality, the solids concentration in the waste tank of such a system would steadily rise throughout the day as it empties. At some undetermined point, the recycle flow would be "switched" back to the recycle tank. The solids which were building up in the waste tank would then be "flushed" into the recycle tank during the final operating period each day. This technique was studied and forms an appendix (Appendix C) to this report. Results of this study showed a 14% savings of both weight and power were possible. Accordingly, the "Low Solids" operation technique has been incorporated into VCD. This required the procurement of a flow-through waste tank, addition of a 3-way flow directional control valve, and modifications to the control circuitry. As discussed earlier, the recycle valve is positioned in accordance with waste quantity. Each time the waste tank empties, the recycle valve is set in the recycle position and latched regardless if a large amount of waste is suddenly received. This latching requirement was an outgrowth of the study. Unlatching is accomplished by VCD shutdown.

Placement of the components within the frame was primarily biased by one gravity operation of recycle and condensate pickups and the small net positive suction head available for delivery to the liquids pump inlets. This consideration resulted in the still being located above the liquids pump. Other components were placed where space and maintenance/access requirements permitted. All components are located within the frame (not the case with SSP) and all interface electrical and plumbing connections are at the rear.

4.3 Subsystem Performance Investigations

A subsystem performance analysis was conducted to provide an analytical model of the fundamental operation of the vapor compression distillation process. The model correlates the effects of basic system operating parameters, such as boiler temperature, input waste composition and characteristics, compressor displacement and efficiency, non-condensable gas production, boiler pressure, film thickness and heat transfer area. These basic operating parameters define water production rate and changes in unprocessed waste composition. They are defined by a large number of other factors such as heat inputs, insulation characteristics, heat flow paths, waste input cycle, still rpm, system operating modes, purge pump flowrates, fluids pump flowrates and others, which have been combined to produce an overall model of the entire subsystem.

To minimize computer use, the model has been divided into three sections. These are the Performance Prediction program, the Steady State Performance model, and the Transient Performance model.

The Performance Prediction program utilizes results of the Transient program at specific solute weight fractions and times during startup to allow investigation of the effect of various feed cycles and feed solids concentrations. Other variables included are waste and recycle tank volumes and start and "switch" volumes. Results of the program include solids profiles of the waste and recycle tanks for any number of days of continuous operation, and prediction of the quantity of condensate produced each day. Also, the feed cycle can be evaluated to determine the number of machine on/off cycles per day, and the approximate daily running time.

Both Steady State and Transient programs simultaneously analyze the thermodynamic and heat transfer performance of the machine. They differ only in that the Steady State program predicts the final equilibrium point, while the Transient model includes mass terms and therefore predicts temperatures and performance as a function of time.

Figure 4-6 presents a temperature-entropy diagram which is representative of the thermodynamic analysis portion of the program. The heavy inverted **U** shaped line represents the vapor dome for pure water. Points 1 to 2 represent the boiling process, 2 to 4 the compression process, 4 to 5 the superheat removal process, and 5 to 6 the condensation process. As the solids content of the feed increases, the properties of the liquid deviate from those of pure water. This deviation with increasing solids is shown by points 2 to 2' and 2 to 2". The difference in pressure between 2' and 3', and 2" and 3" represent boiling point suppression due to the solids content of the feed liquid.

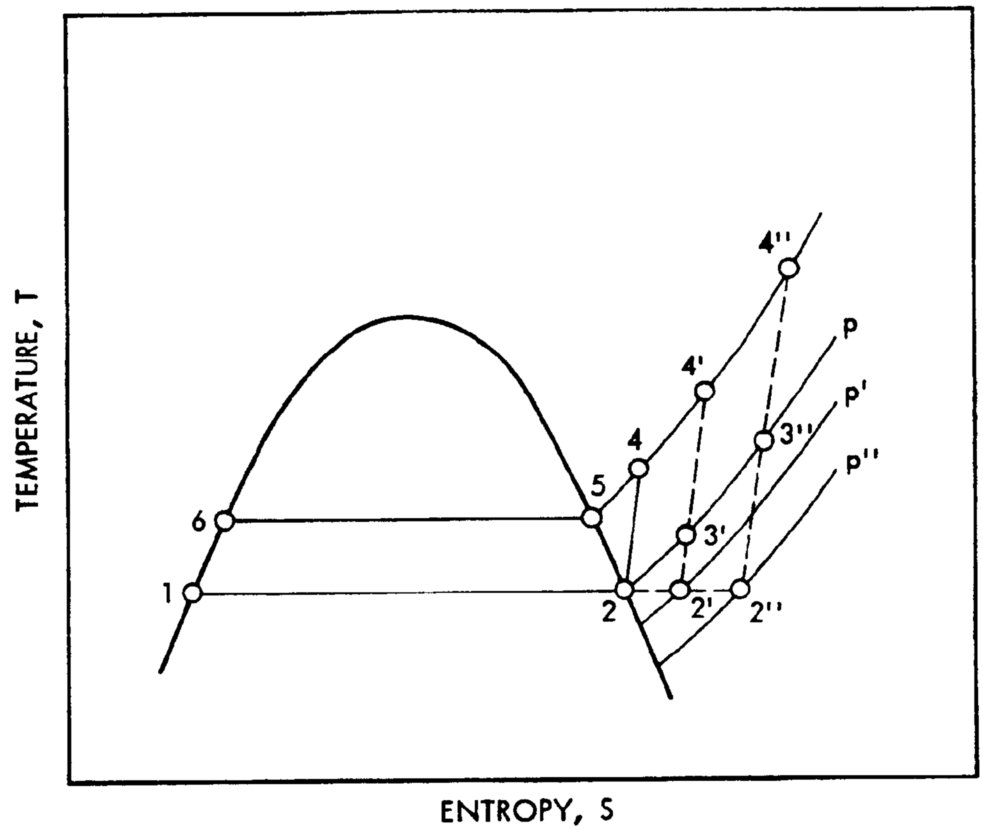

Figure 4-6 Representative Temperature Entropy Diagram for VCD

Items considered in the thermodynamic analysis include fluid property calculations, compressor and motor performance, and boiling and condensing heat transfer coefficient prediction. Fluid properties are calculated by equations and curvefits of literature data (Ref. 1). Important mechanical characteristics which are included are the compressor displacement and efficiency (both volumetric and mechanical), motor torque-speed characteristics and efficiency, the waste and recycle tank size, boiler and condenser heat exchange areas, and purge pump flowrate.

The heat transfer portion of the program consists of a nodal analysis, as shown in Figure 4-7. Each important element of the machine is assigned a node. Resistances representing the combined effects of convection, conduction, and radiation between nodes are then calculated. The Transient program also assigns masses to each nodal point.

During program operation, an estimate is made of the condenser and boiler temperatures. The program then calculates fluid properties and compressor and motor performance, and evaluates the boiling and condensing coefficients and heat loads.

These are then input to the nodal analysis, and the results for these temperatures are compared with the initial assumptions. If they differ, new assumptions are made, and the program iterates until temperature balance is achieved.

Results of the Steady State program are the equilibrium temperatures at each nodal point, and the power consumption and condensate production rate. The Transient program supplies these same items as a function of operating time. Provisions for both recycle through the waste tank and recycle tank are provided. Additional details of the programs are provided in Appendix D.

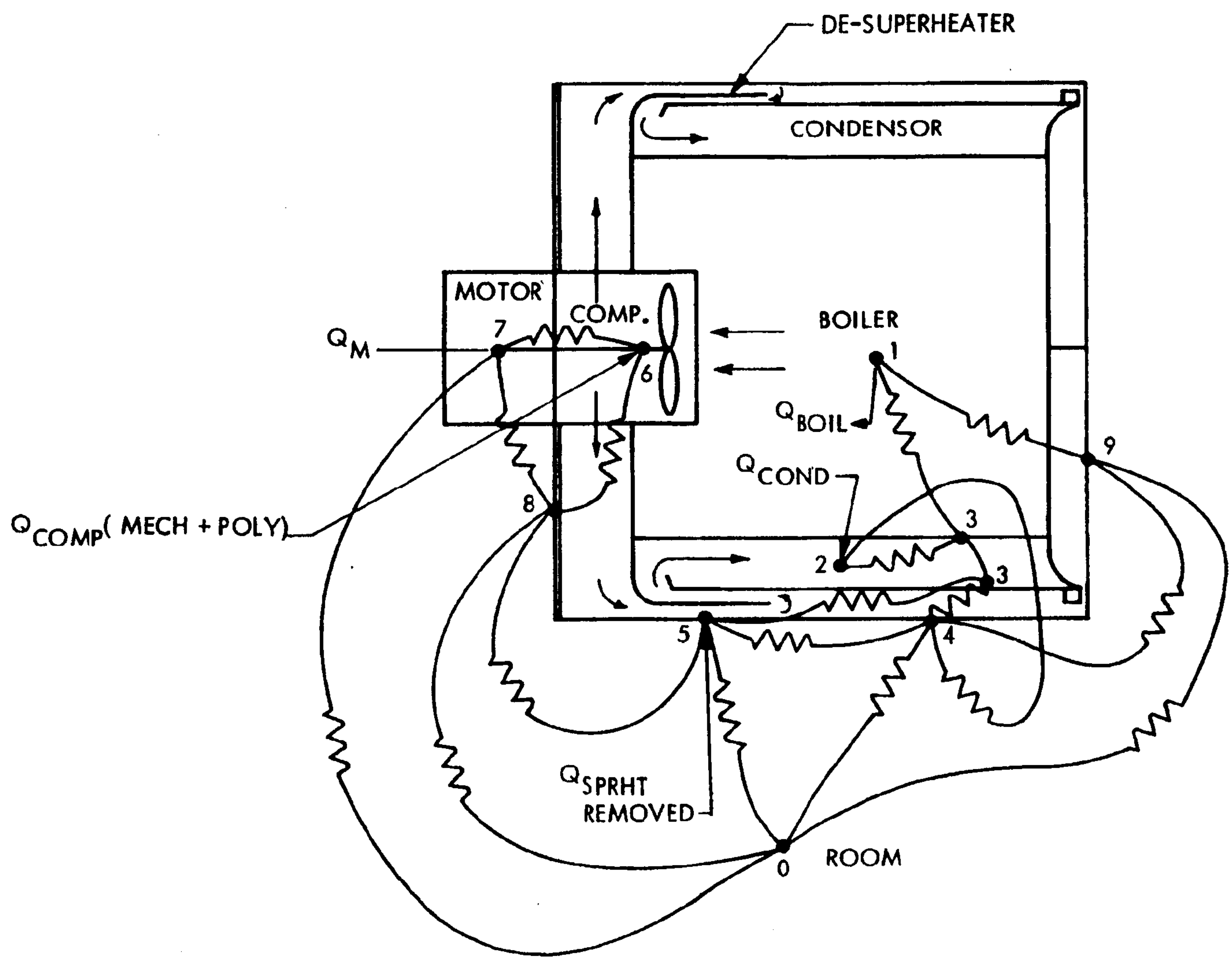

Figure 4-7 VCD Heat Transfer Nodal Model

Section 5
VCD SUBSYSTEM TEST PROGRAM

The test program was divided into two major sections: verification and baseline testing. The object of verification testing was to certify subsystem functionality, and design performance levels being met. The object of baseline testing was to develop comprehensive operating characteristics data in one-g conditions which later could be used to quantify dispersions in parameters encountered in zero-g testing. The subsystem configurations for all 27 runs comprising verifications and baseline testing are tabulated in Table 5-1.

5.1 Verification Tests

The mass of the VCD module and its major components was measured with the results shown in Table 5-2. The power requirements are summarized in Table 5-3.

A pump down test of the still with the dry vane purge pump resulted in an ultimate vacuum of 2.67 kNm^{-2} (20 torr) being achieved in one hour. All components operating above ambient pressure were checked for leakage by observing pressure decay. Similarly, all components operating in vacuum were checked for leakage by observing vacuum decay. No leaks either in pressurized or vacuum components were observed. The still is extremely leak tight, and the liquids pump roller occlusion was found very effective in maintaining subsystem vacuum.

The controller was exercised on the bench with dummy inputs verifying proper output commands for every conceivable pathway through the operational modes. Correct performance in all cases was noted. The

Table 5-1 VCD Test Configuration

Run No.	Waste Tank Lab.	Waste Tank RLSE	Liquid Pump SSP	Liquid Pump RLSE	Drive Motor SSP	Drive Motor RLSE	Purge Pump Lab. Oil	Purge Pump Diaphragm	Purge Pump RLSE	Remarks
1	X		X			X	X			
2	X		X			X	X			Incline Still, Insulate Still
3	X			X		X	X			Incline Still, Insulate Still
4	X			X		X	X			Incline Still, Insulate Still + L. Pump + Rec'y Tank, T/C's on C'Denser + Liq. Lines
5	X			X		X	X			Stippled Drive Pulleys, Enlarged Drydown Holes Installed Comp Exh T/C
6	X			X		X	X			Same as 5.
7	X			X		X	X			Same as 6
8	X			X		X	X			Same as 7 except Small Recycle Tank
9	X		X			X	X			Level Still, Insulate Still
10	X		X			X	X			Same as 9.
11	X		X			X	X		X	Same as 10.
12	X		X			X	X		X	Same as 11.
13	X		X			X	X		X	Same as 12.
14	X		X			X		X	X	Removed Insulation
15	X		X			X		X		Changed Compressor Brgs.
16	X		X			X		X		Same as 15.
17	X		X			X		X		Same as 15.
18	X		X			X	X			Same as 15.

Table 5-1 VCD Test Configuration (continued)

Run No.	Waste Tank		Liquid Pump		Drive Motor		Purge Pump			Remarks
	Lab.	RLSE	SSP	RLSE	SSP	RLSE	Lab. Oil	Diaphragm	RLSE	
19	X		X			X	X			Same as 15.
20		X	X			X	X			Insulated Still
21		X	X			X	X			Same as 20.
22		X	X			X	X			Same as 20.
23		X		X		X	X			Same as 20.
24		X		X		X	X			Same as 20.
25		X		X		X	X			Instl. Big Rec'y Tank
26		X		X		X	X			Same as 25.
27		X		X		X	X			DE-Superheater Off

Table 5-2

Mass Statement

Item		Mass kg (lb)
VCD Module (Dry)		175.9 (387.45)
Vapor Compression Still Assembly (w/insulation)	61.4 (135.25)	
Controller	8.3 (18.25)	
Liquids Pump	18.4 (40.7)	
Waste Tank (empty)	18.2 (40.0)	
Recycle Tank (empty)	9.2 (20.25)	
Structure, plumbing, wiring, fans	60.4 (133.0)	

Table 5-3

Power Summary

Item	Condition	Watts
VCD Module	H_2O wastestock calibration run No desuperheater, lab. vac. pump	38 AC + 107.3 DC
Still	Dry Run (PC1=1.2, CDP=1.0, NX=250)	89.9 DC
Controller	No Change W/Display On or Off	16.5 AC
Purge Pump	No Head Rise	72 AC
Purge Pump	Dead Headed (10.9 torr)	88 AC
Purge Pump	On Test Rig (PC1=28, TE=25)	68 AC
Purge Pump	On VCD Module	53 AC
Liquids Pump	On Test Rig	25 AC
Boost Pump	While Operating, Duty Cycle 10%	40 AC
Diverter Valve	While Operating, Duty Cycle ≈ 0	40 AC
Shutoff Valve	While Operating, Duty Cycle ≈ 0	40 AC
Recycle Valve	While Operating, Duty Cycle ≈ 0	40 AC

controller was then connected to the subsystem and all functions once again checked. During the course of the first few runs, those sensors, such as liquid level sensor (LLS), evaporator temperature (TE), and conductivity monitor (CM) which were relatively inaccessible were operated by actually creating an off standard condition and observing proper controller response. Other sensors such as condenser pressure (PC), compressor delta pressure (CDP), waste quantity (W1), waste fluid pressure (PF), and centrifuge speed (NX) were manually manipulated and the proper operation of the VCD subsystem verified. Other sensors which provide a display to the operator but are not controller functions were checked for proper operation. Sensors were calibrated and display panel buffering circuits adjusted.

A total of 6 runs were made during verification testing to exercise various aspects of the VCD subsystem. The first two runs were made without RLSE waste tank, purge pump or liquids pump while these components were being repaired. Run 3 was the first subsystem test with the RLSE liquids pump returned to service. Run 4 was a thermoequilibrium run. In preparation for this run, 50.8 mm (2.0 in.) of fiberglas insulation was applied over all surfaces of the still, except the electronics section of the drive motor; to the recycle tank (SSP); and to the liquids pump (RLSE).

Thermocouples were emplaced at three positions on the outside surface of the still cylindrical section, on the still end plate, on the still waste feed input and recycle output tubes, the drive motor stator housing, and to monitor room temperature. The VCD was started and when boiler temperature became stabilized at 32.1°C (89.8°F) the insulation was removed from the liquids pump. No change in boiler temperature was noted after one hour. Then the recycle tank insulation was removed. No change in boiler temperature was noted after one hour so the VCD was stopped. The thermal transient is shown in Figure 5-1. The conclusions drawn from this test were that insulating the liquids pump and recycle tank was unnecessary. Attainment of steady state operation took 5.5 hours. As

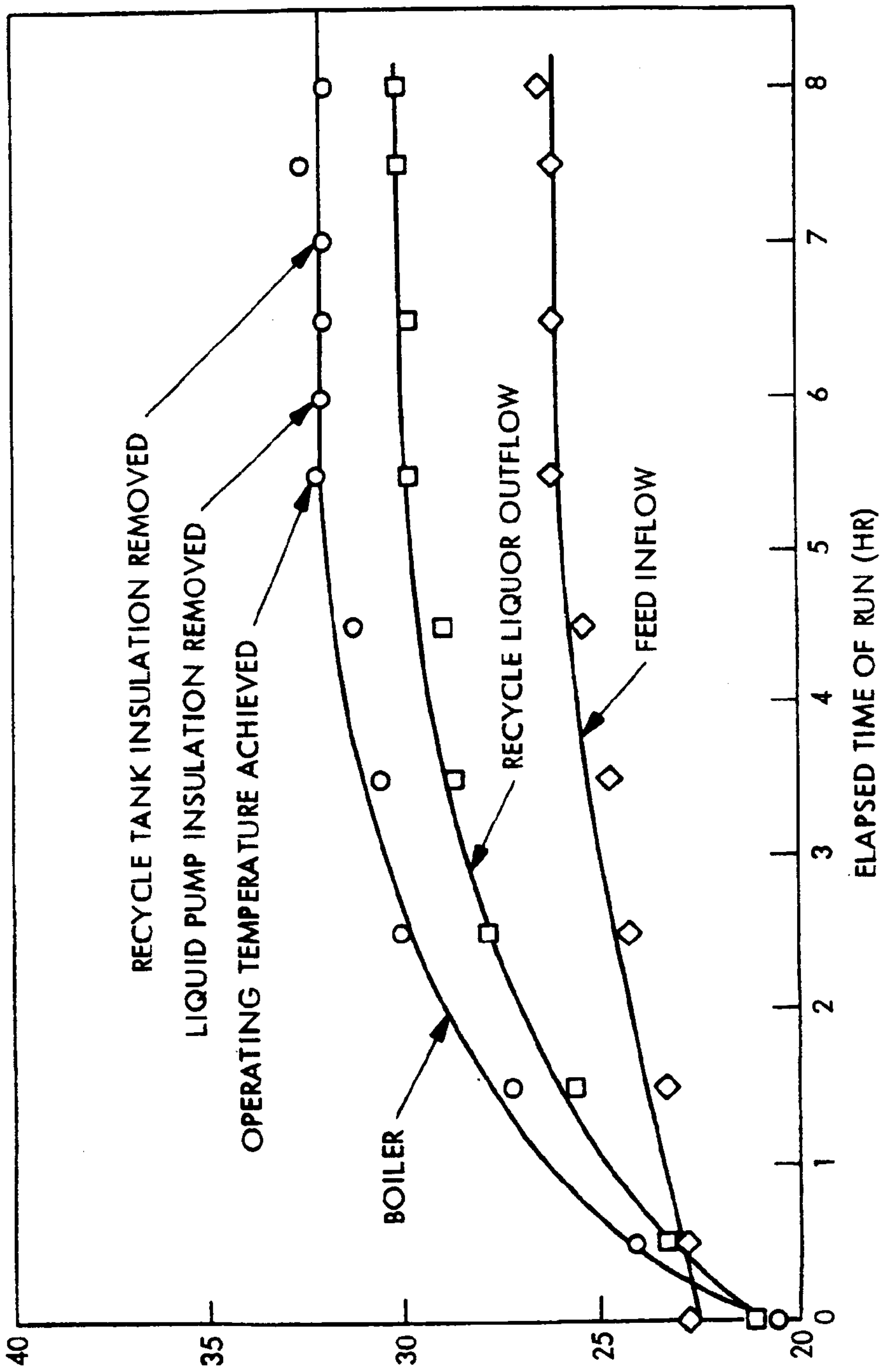

Figure 5-1 VCD Thermal Transient

can be seen, the temperature difference between feed inflow and recycle outflow is significant and contributes to the thermal time constant.

It was determined in these first few runs that normal drydown was not being achieved. With lengths of translucent polyflow tubing installed in the three liquid lines between still and liquids pump, visual observations of flow could be made. Typically, recycle flow would be seen to go to zero about 5-10 min. after DRYDOWN commenced. At this point, condensate and feed flow would reduce and equalize at a value considerably less than during RUN, and the compressor delta pressure would rise either very slowly, or else stop rising altogether. After considerable time (up to 60 min.) in this mode, the diverter valve was manually placed in the non-divert position and condensate was extracted from the subsystem. Eventually, the boiler became dry and compressor delta pressure rose. However, even then it was not achieving the proper shutoff value (15 mmHg).

These developments caused several steps to be taken: 1) The still was inclined a small amount favoring recycle outflow. 2) The still was opened and 377 μm^3 (377 ml) of water was found in the boiler. 3) The drydown holes in the film thickness control dam were checked for tangency with boiler I.D. 4) The recycle pickup was checked for proper immersion depth. Runs 5 and 6 were made expressly to examine this drydown problem. No improvement was noted. Coupled with this anomaly was a lower condensate production rate. All indications were that the compressor was not performing properly. This led to the compressor testing and bearing seal reversal reported under distillation unit component developments. The delta pressure characteristics of the distillation unit were vastly improved by the seal reversal, but the inability to achieve normal drydown persists.

5.2 Baseline Test

The baseline test was conducted to develop a body of data which would provide a yardstick to measure the effects of zero gravity VCD operation. It was originally planned to operate the VCD for 30 equivalent days

(16 hrs/day) in order to execute at least one complete solids accumulation cycle in the recycle liquor tank. It was also planned to conduct one 5 day continuous test i.e., 5 consecutive days of 16 hr/day operation.

Previous experience gained in familiarization tests indicated that accumulation of high percentages of solids in the recycle tank was difficult to achieve if the system configuration was in constant flux. The opportunities to dilute the recycle liquor are numerous. It was decided that accumulation of two accelerated complete solids scans would be more meaningful and provide more useful data than one scan and, in the event of mishap, the likelihood of achieving at least one scan would be probable. The small acrylic recycle tank constructed for familiarization tests was installed in lieu of the regular 30 day recycle tank. This small tank contains 2.253 kg water. As mentioned before the calculated solids in a wastestock composed of pretreated urine/flush water is 1.57-2.35% by weight. On this basis, a solids scan should be accomplished after processing 57.5 kg (126.6 lb) wastestock, or 43 hours of operation.

The baseline test was accomplished per the run schedule shown in Table 5-4. The first solids scan was accomplished in runs 8 through 19 using pre-treated urine and flush water exclusively as waste input. It was pre and post ceded by "calibration" runs using distilled water as waste input. The calibration runs were to reveal performance degradation as a result of boiler or condenser contamination. At the conclusion of run 19, all tanks and lines were flushed, but the distillation unit was untouched. The recycle liquor was drained and stored.

The second solids scan was accomplished in runs 21 through 24. In this scan, various waste stocks were prepared as input. Run 21 utilized pre-treated hyperfiltrated brine only. Run 22 used a 50% mixture of pretreated

Table 5-4 Baseline Test Schedule

Run No.	Purpose	Wastestock
7	Calibration	Water
8	First Solids Scan	Pretreated urine/flush water
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19	First Solids Scan	Pretreated urine/flush water
20	Calibration	Water
21	Second Solids Scan	Pretreated R.O. Brine
22		Start 50% pretreated R.O. Brine + 50% pretreated urine/flush water thence 100% pretreated urine/flush water
23		Pretreated urine/flush water
24	Second Solids Scan	50% pretreated R.O. Brine + 50% pretreated urine/ flush water
25	Calibration	Water
26	Purge Flow Data Acquisition and flush down drydown	Pretreated urine/flush water
27	No desuperheater	Water

hyperfiltrated brine with 50% pretreated urine/flush water to start, but then reverted to 100% pretreated urine/flush water for makeup after the 50/50 mixture was processed. At the conclusion of the second solids scan, run 24 was made with the same 50/50 mixture input as for run 22. Another water calibration run followed.

Runs 26 and 27 were special runs to test specific aspects of VCD. In run 26, special instrumentation was added to quantify VCD purging requirements. Run 27 tested the effect of desuperheater removal. When removing the desuperheater, the distillation unit was opened for the first time since baseline testing started. The conditions were documented. The still was cleaned, pumped down, and run dry for tare power measurements prior to start of run 27.

The accumulation of solids in the recycle liquor is shown versus cumulative wastestock processed in Figure 5-2. The prediction is tracked for about the first half of the first scan, then a marked deviation occurs. Reasons put forward for this are 1) that precipitation of solids occurs as the concentration increases, 2) that a good determination of solids is difficult to make at the higher concentrations, and 3) that the test urine composition is more dilute than expected. The concentration rate of the second scan started out less than the first as expected, but exceeded it later on. One reason for this may be due to the smaller number of longer runs accomplished in the second scan. Precipitation of solids may be enhanced by start stop transients, or elapsed time.

Processing rate as a function of solids accumulation is shown in Figure 5-3. Two relationships are plotted showing two different evaporator isotherms. As expected, production rate decreased as solids increased. Also, the decrease of only 1.45°C (2.61°F) produced a marked decline in production.

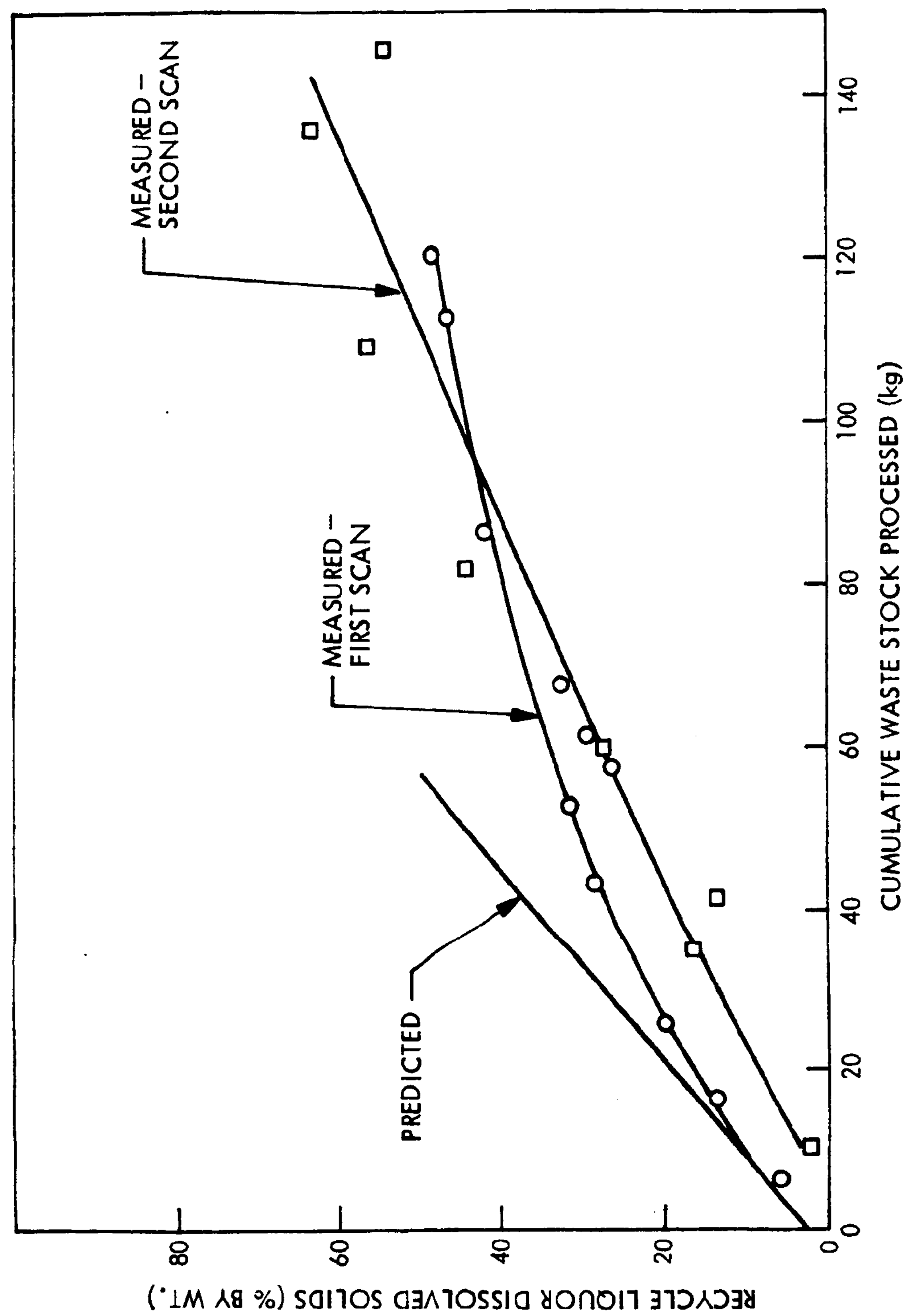

Figure 5-2 Solids Concentration Rate

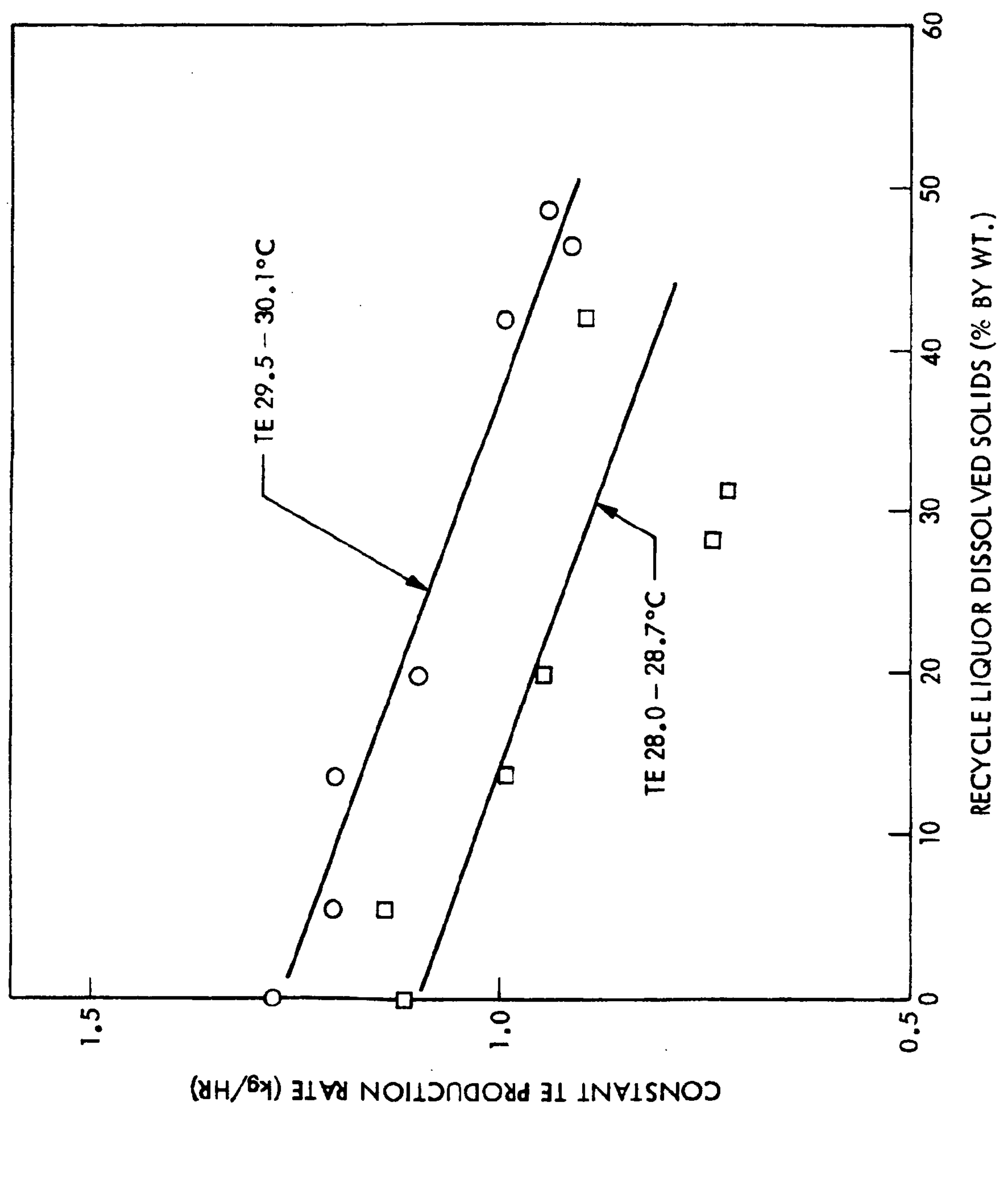

Figure 5-3 Condensate Production vs Solids and Temperature

The effect of temperature on condensate production is further illustrated in Figure 5-4. In this figure condensate production increases with increasing boiler vapor space temperature are plotted for two widely different solids concentrations.

The first solids scan was performed entirely without the RLSE waste tank while it was being repaired by the vendor. Solids were being concentrated by the traditional mode of constantly directing all recycling flow through the recycle tank. During the second solids scan when the RLSE waste tank was installed, the "LOW Solids" recycling technique was used. An example of the benefit of this technique is shown in Figure 5-5. This curve shows the rapid decline in condensate production when the recycling mode switches from waste tank to recycle tank. Had the recycle liquor been flowing through the recycle tank all the while, the production rate would have been much lower. It should be noted that samples drawn for recycle solids determinations are valid only after flow has "switched".

The effect of this transient not only decreases condensate production, but it generally decreases water quality as well. Whenever a recycle "switch" occurred, a high conductivity DIVERT occurred which was generally manually overcome. Figure 5-6 shows the effect of recycle solids increases on condensate conductivity. In the first scan, a steady upward level of conductivity was noted. The second scan was somewhat complicated by the "switching" of recycle flow. It was difficult to determine if subsystem degradation was taking place with all the transients occurring. Therefore, the best, or lowest condensate conductivities observed in the time span between recycle flow "switches" (when recycling through the waste tank) were plotted. If an upward trend were observed it would indicate a fouling condition occurring. As it turned out, no trend was found, therefore it is concluded that increased condensate conductivity is mostly a function of recycle liquor rather than fouling of boiler or condenser.

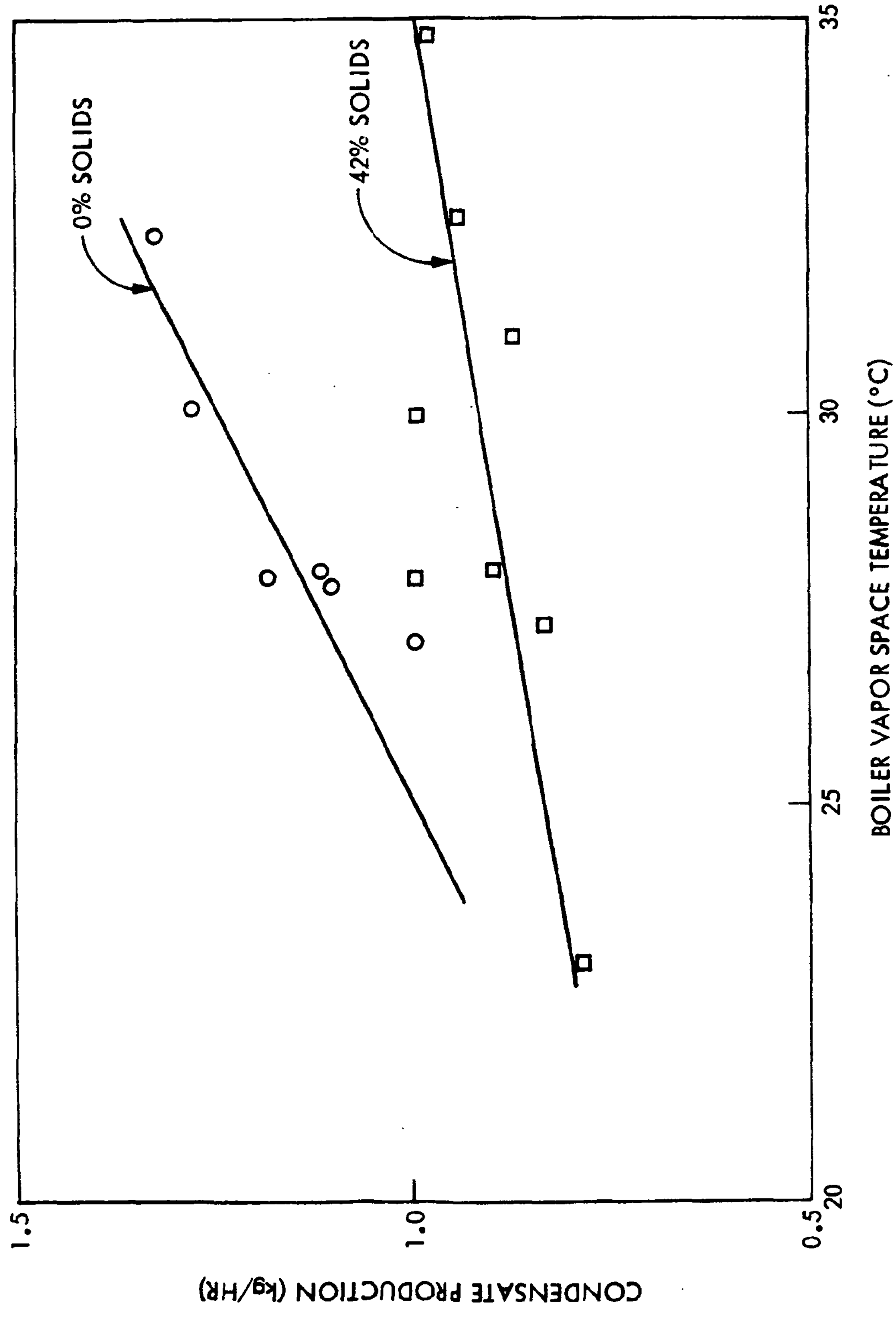

Figure 5-4 Effect of Boiler Temperature on Condensate Production

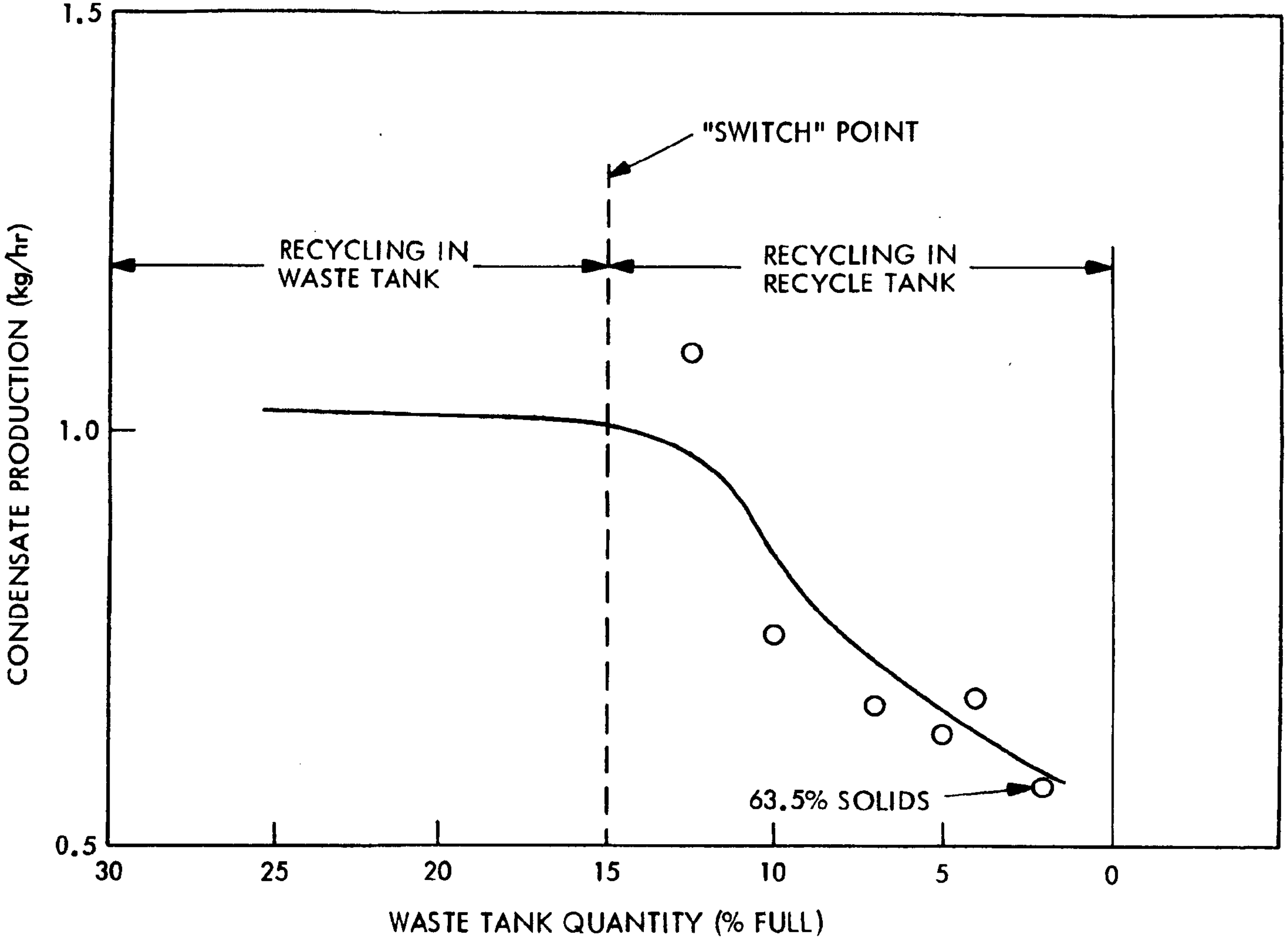

Figure 5-5 Low Solids Recycling Technique at "Switch" Transient

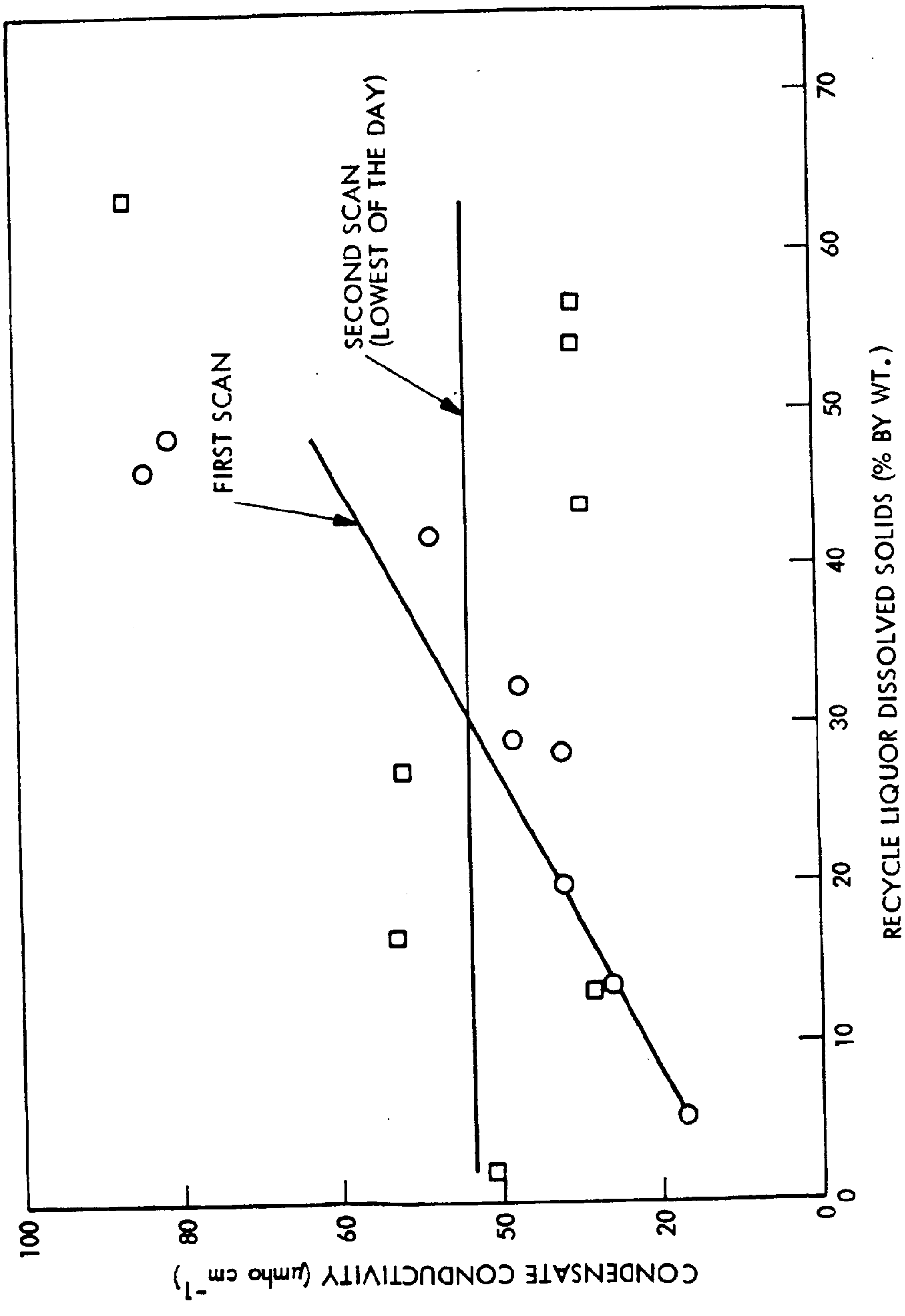

Figure 5-6 Condensate Conductivity vs % Solids

At no time was there ever any difficulty in maintaining control of the recycle liquor. Periodic pH measurements were all under 2.5. No unusual precipitations were observed, and when emptying the recycle tank, the contents poured out freely. The outflow of the recycle tank was purposely taken off the bottom in an effort to produce blocked flow. None ever was attained These results suggest that recycle loop filtration is not required.

Table 5-5 summarizes the production history of the baseline test. The overall water recovery ratio was 0.972, and the total run time was 333.26 hours.

Condensate was sampled periodically at the end of the first solids scan, and throughout the second solids scan. These samples were analyzed and the results presented in Table 5-6. All pH values fell between 3.3 and 4.1. No trends are indicated by any of the parameters listed. Condensate samples extracted during recycle flow "switched" to recycle tank are indicated. No explanation is apparent for the abnormally high TOC and TC of the sample taken at 1500 on 16 March 1978.

Run 26 was accomplished for the sole purpose of quantifying the purge requirements. A special delta pressure setup was made to determine what, if any, pressure drop was occurring in the purge conduit within the still. In addition, the flow of non-condensibles was measured. Wastestock was pretreated urine/flush water. Recycle liquor solids ratio was 2%.

No delta pressure was observed in the purge conduit. Non-condensible purge flow was measured at 0.125 cc/min at standard conditions.

A number of attempts to induce compressor delta pressure rises and condenser pressure rises by closing the purge pump inlet valve was made. The rise in condenser pressure was 10.6-16 Nm^{-2} (0.08-0.12 torr)/min. These tests are indicative of an extremely tight system, and low liberation of non-condensibles.

Table 5-5 Baseline Test Production Summary

Run No.	Time (hr)	Total Condensate Production (kg)	Total Purge Water (kg)	Total Waste Input (kg)	Best Condensate Production (kg/hr)
7	8.82	7.875	0.114	7.718	1.320
8	5.23	2.970	0.085	2.429	0.586
9	6.00	5.720	0.125	6.992	1.300
10	12.10	10.925	0.291	13.075	1.205
11	19.20	18.920	0.576	18.182	1.220
12	10.80	6.370	0.395	6.742	0.750
13	11.28	6.000	0.394	8.808	0.960
14	17.70	1.415	0.012	2.906	0.829
15	3.58	2.050	0	3.292	0.980
16	7.00	6.235	0	6.265	0.930
17	3.35	2.050	0	1.998	0.790
18	23.00	20.086	0.272	21.270	0.998
19	31.00	27.655	0.402	28.307	1.155
20	3.30	2.955	0.048	2.697	1.030
21	4.60	3.705	0.072	3.541	1.075
22	31.10	30.770	0.599	29.551	1.095
23	101.80	97.870	2.164	100.897	1.127
24	11.80	10.235	0.205	12.248	0.995
25	7.10	6.770	0.140	7.416	1.055
26	7.30	7.644	0.155	7.866	1.470
27	7.20	10.005	0.105	10.562	1.330
	333.26	288.225	6.154	302.762	

Table 5-6 Condensate Analysis

Run No.	Sample Date & Time	pH	Conductivity (μmho cm^{-1})	TOC (ppm)	TC (ppm)	Avail. Iodine	Recycle Solids (%)	Waste-Stock	Remarks
19	3 Mar 78 1000	3.5	92	54	56	Less Than 1 ppm	46.51	P.T. Urine/Flush Water	
19	3 Mar 78 1600	3.6	94	47	49		48.64	" " " "	End 1st Scan
20	7 Mar 78 1700	3.8	84	28	35		-	H_2O	Water Cal.
21	8 Mar 78 1500*	4.1	20	16	20		-	P.T. R.O. Brine	Start 2nd Scan
22	9 Mar 78 1100*	3.3	22	29	43		2.15	50/50 R.O. + Urine/ Flush All P.T. Urine/ Flush at 1200	
22	10 Mar 78 0900	3.7	36	22	27		-	P.T. Urine/Flush	
22	10 Mar 78 1500*	3.6	46	21	24		16.68	" " "	
23	13 Mar 78 1500	3.7	40	24	28		13.40	" " "	
23	14 Mar 78 1100*	3.7	56	24	24		27.17	" " "	
23	14 Mar 78 1400	3.4	108	33	37		-	" " "	
23	15 Mar 78 0900*	3.5	120	47	49		44.11	" " "	
23	15 Mar 78 1500	3.8	30	25	26		-	" " "	
23	16 Mar 78 1000*	3.5	58	42	46		56.74	" " "	
23	16 Mar 78 1054*	3.4	62	47	52		-	" " "	
23	15 Mar 78 1500	3.8	28	395	513		-	" " "	
23	17 Mar 78 0900*	3.5	49	33	39		-	" " "	
23	17 Mar 78 1000*	3.3	96	38	44		63.45	" " "	
24	20 Mar 78 1100	3.7	36	36	45		-	50/50 R.O.+Urine/Flush	
24	20 Mar 78 1400	3.9	34	83	100		54.36	" " "	End 2nd Scan

*Recycle Flow Switched to Recycle Tank

After this test, the still was opened. The results of this examination are as follows:

Centrifuge bearings. When the centrifuge was spun up by hand, it took 52 seconds to come to rest.

Outer Shell. Unremarkable.

Condenser Cover Plate. A small amount of black greasy deposit on inner surface near return scoop exit.

Hub. The recycle passage was dirty with brown flakes of deposition throughout. Made removal more difficult than normal.

Condensate collection cone. Unremarkable.

Recycle Closure Plate. (See Figure 5-7) Heavy deposition of light brown soft material on inner surface. Deposition was heaviest at greatest radius with bare spots at inner radius.

Recycle Pickup Cone. (See Figure 5-8) Flaky hard deposits with thickness and color variations were found on the pickup side. The color was darkest, and the deposits thickest nearer the pickup. The stratification of deposits was not radial, but more like water lines with the pickup being down. In the still, the pickup is on the horizontal plane, therefore the deposition pattern must be wake related. The opposite side was relatively clean. The inner surface (boiler side) had a similar gradient, but was all in all much less fouled. (See Figure 5-9). Some random flakes were noted. The liquid level switch assy. was clean. The feed manifold fairly clean with no holes blocked.

Boiler. (See Figure 5-10) The boiler was relatively clean. Most deposition was near where the feed manifold sprays feed on the boiler surface. The patches of deposit shown on the boiler cylindrical surface are very thin and powdery. No pattern of pooling or high spots was noted.

Evidence of carry over is seen on the bearing cartridge and nearby where the demister was removed.

Condenser. Absolutely clean.

Desuperheater. Absolutely clean.

Central Shaft. (See Figure 5-11). Mild deposition on outer (boiler) surface of flange. Medium to heavy deposition inside of flange. Gravity orientation noted.

Compressor. Similar to central shaft. Turns freely. Minor corrosion on lobes. Gear lube dry.

Jack Shaft and O-ring Drive. Unremarkable.

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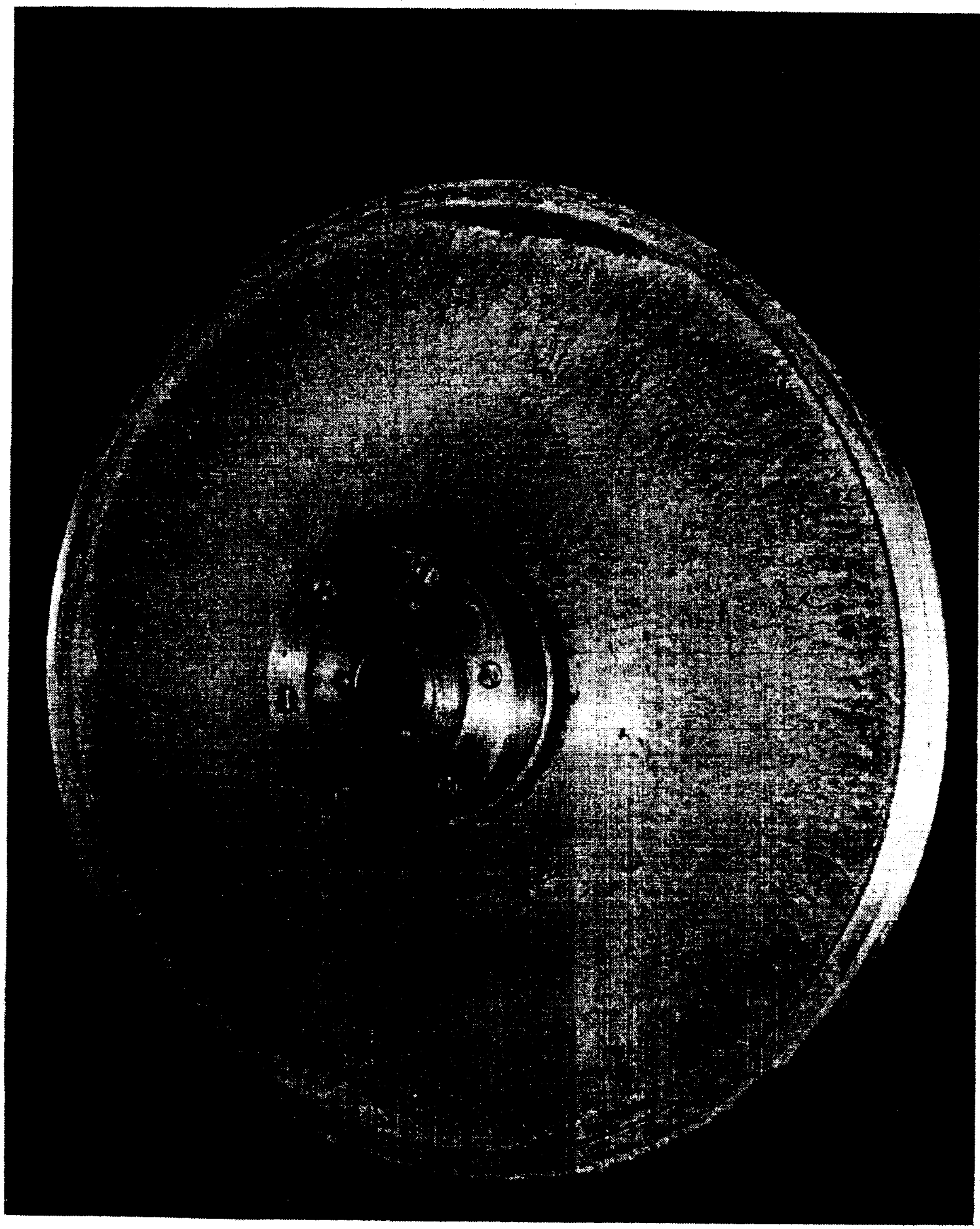


Figure 5-7 Recycle Closure Plate Condition After Baseline Testing

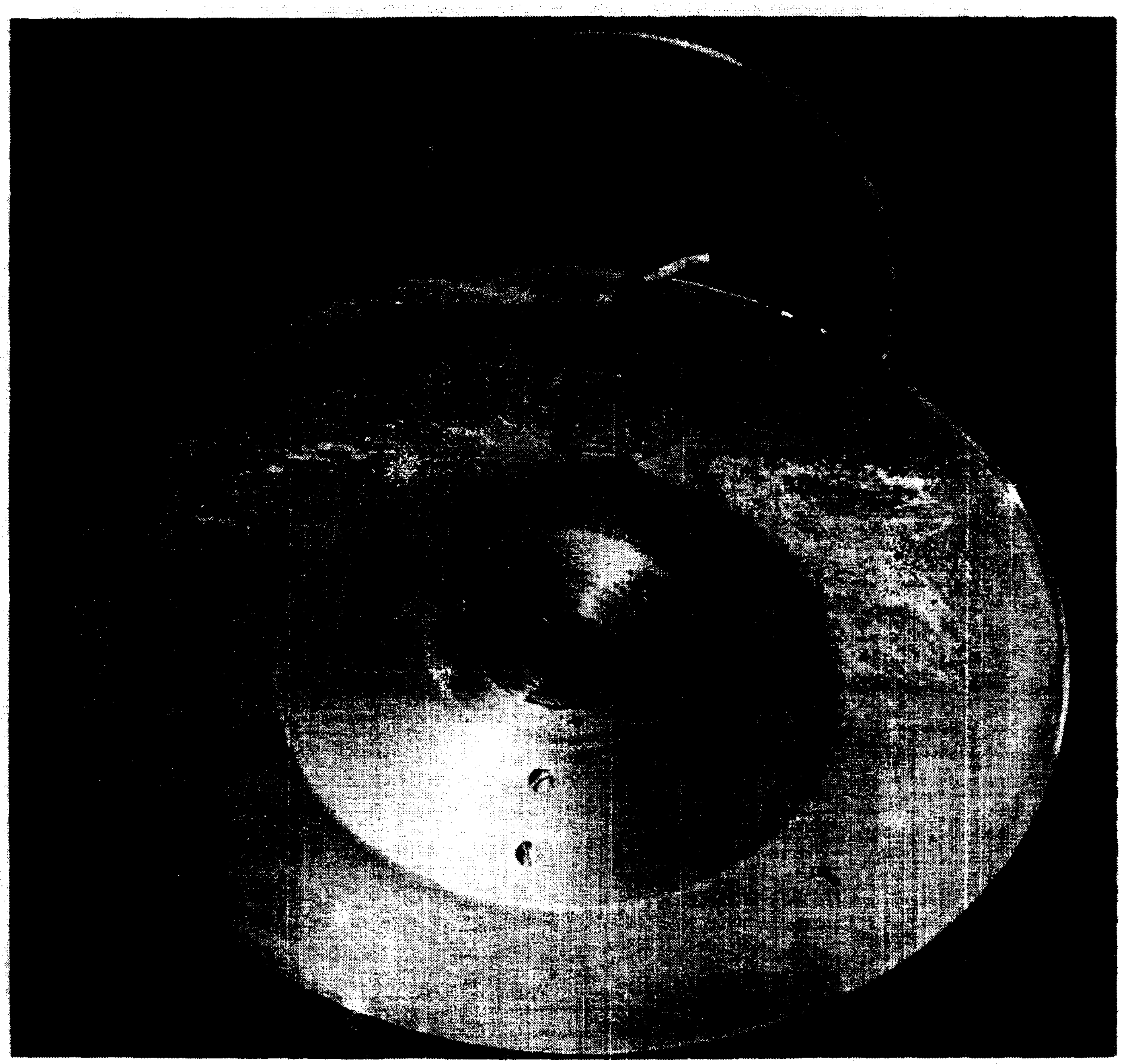


Figure 5-8 Recycle Pickup Tube Area Condition After Baseline Testing

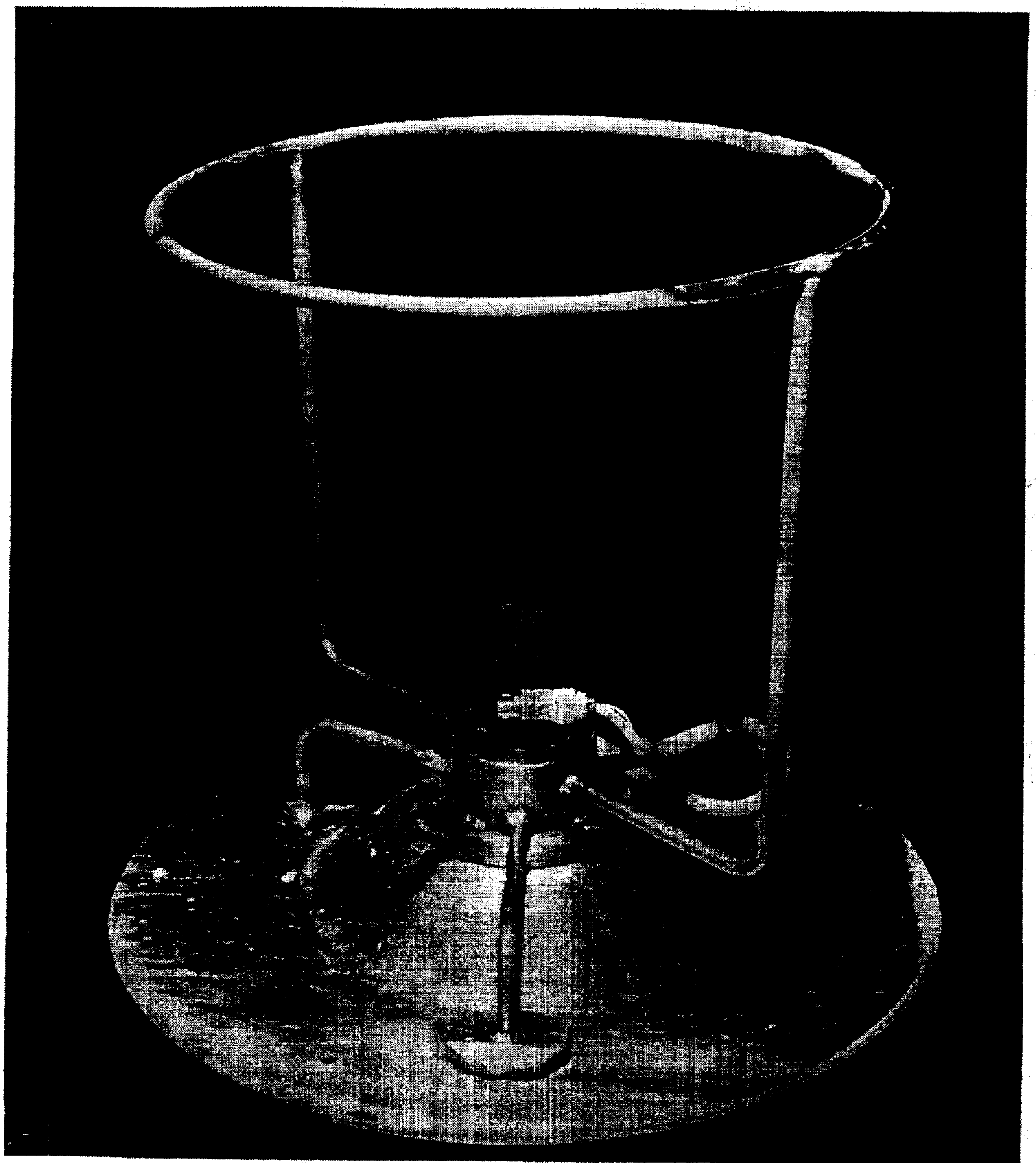


Figure 5-9 Feed Manifold and Liquid Level Sensor Condition After Baseline Testing

Figure 5-10 Boiler, Condenser, Desuperheater Condition after Baseline Testing

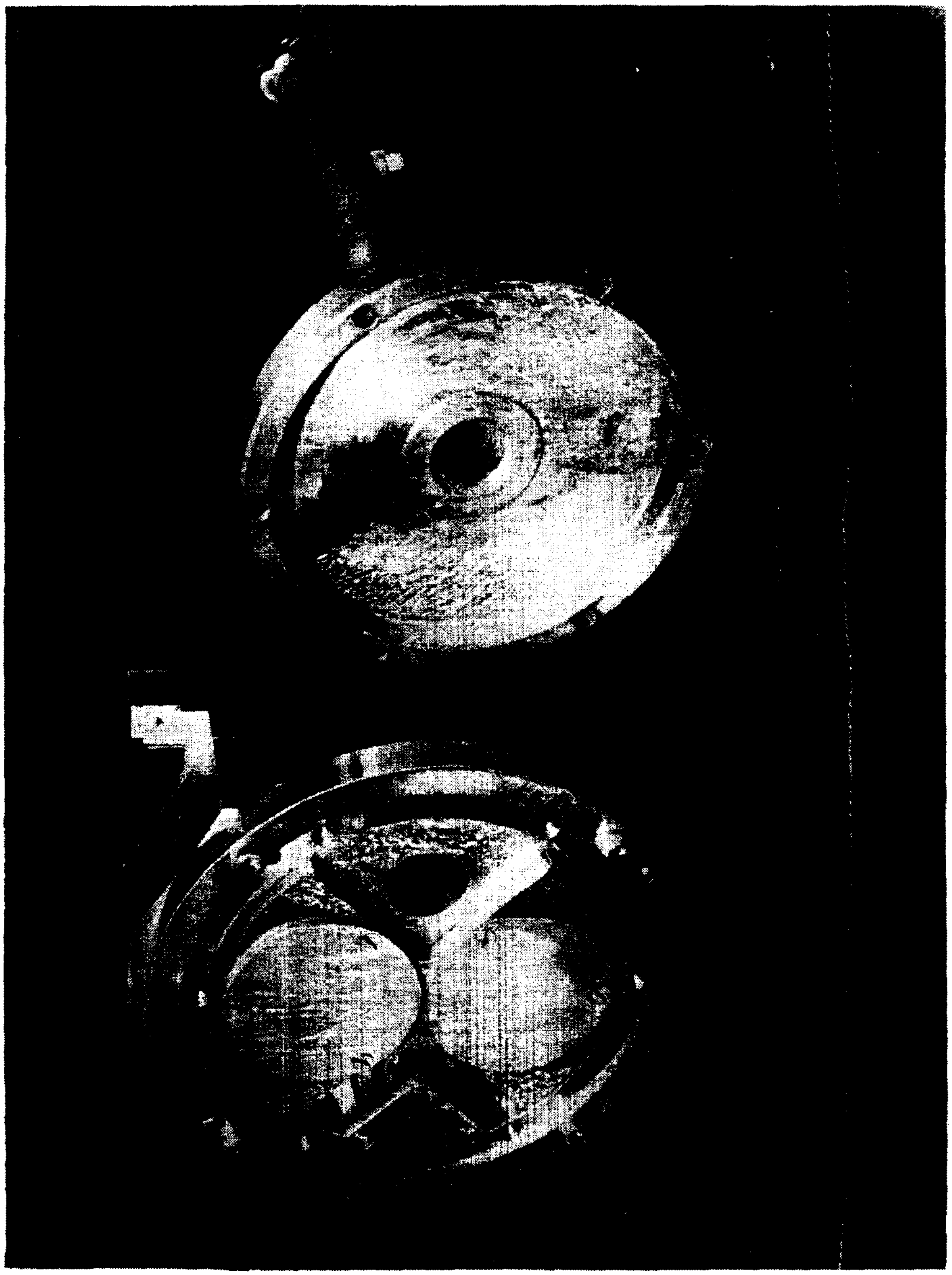


Figure 5-11 Central Shaft and Compressor Condition After Baseline Testing

All parts were cleaned by use of soap and cold tap water. In some areas of hard deposition, steel wool was used. The heaviest deposition was also the softest and removed very easily.

After removing the desuperheater, the still was reassembled and pumped down for a tare power measurement. With a condenser pressure of 159 Nm^{-2} (1.2 Torr), a compressor head rise of 133 Nm^{-2} (1 mmHg) and centrifuge speed of 255 RPM, the drive motor tare power was measured as 89.9 W.

Run 27 using water wastestock produced a peak condensate production of 1.33 kg/hr. with compressor delta pressure of 387 Nm^{-2} (2.9 mmHg) and condenser pressure of 4.13 kNm^{-2} (31 torr).

Appendix A
Test Operations Plan

1.0 Purpose. The purpose of this document is to outline the procedures for operating and testing VCD.

2.0 Setup Requirements. (Refer to Figure 1) The VCD module dry weight is 387 lb., and has a high center of gravity. It should be firmly secured to a stable base. It is helpful to have the base elevate the module about 10 inches to reduce operator stooping. Since the still (C/N 29) has a heavy rotating centrifuge, it is helpful to brace the top of the module to some portion of the building structure to minimize vibrations.

2.1 Interface Requirements

2.1.1 Electrical Interfaces. The VCD module requires 400 Hz, 3 phase, 208 V (line to line), 2.5 amp per phase AC and 29.5±2.5 VDC, 10 Amp DC power with current limiting and ammeter. The normal AC amperage is 0.25 A per phase, but when running in the still after major modifications, an AC motor is used which requires higher current supply. The Display Panel uses 60 Hz, 1 phase 115 V, 5 A, AC power. The phase sequence and polarity requirements are marked on the power cables. Two Auxiliary DC fans are powered in series connection at the same 29.5 VDC and have their own power cable.

2.1.2 Mechanical Interfaces.

2.1.2.1 Pressurant (11G6-09). Ordinary water pumped GN_2 from a K bottle is satisfactory. Connect and adjust pressure to 5 psig.

2.1.2.2 Urine input (11L4-10). The pretreated urine input is best delivered from a 1-gravity tank using a 10 psig pressure source. If none is available any transfer pump developing 10 psig is adequate.

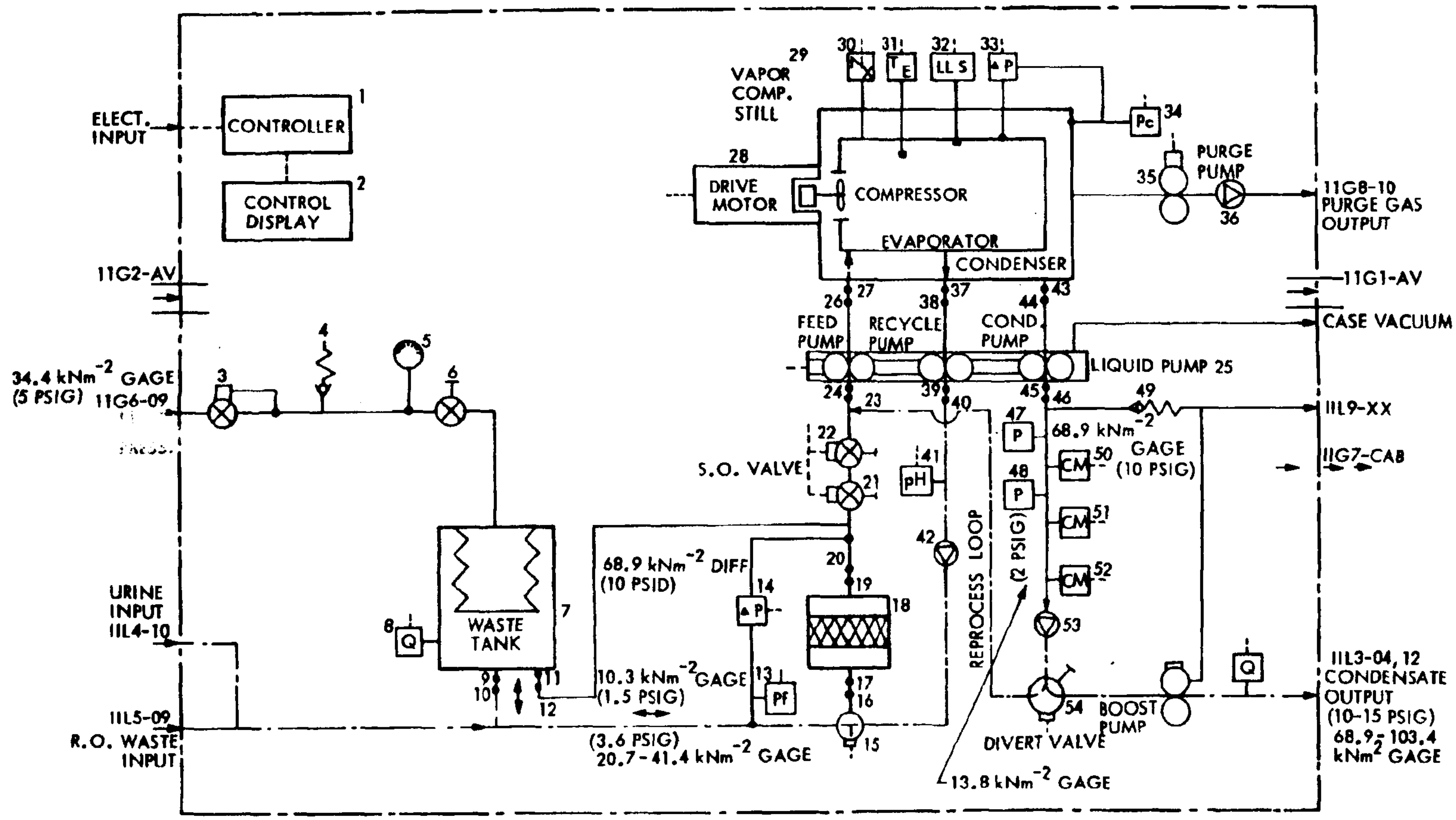


Figure 1 RLSE Vapor Compression Distillation (VCD) Module Schematic

2.1.2.3 R.O. Waste Input (11L5-09). Pretreated R.O. brine input is best delivered from a source similar to that for pretreated urine.

2.1.2.4 Purge Gas Output (11G8-10). This gas is normally discharged to the laboratory.

2.1.2.5 Case Vacuum. This connection is for a vacuum source other than the purge pump (C/N 35). The vacuum need only be 40 torr, and is required only to assist tube reflation in the liquids pump (C/N 25).

2.1.2.6 Condensate Overflow (11L9-XX). In case of blockage or breakage of condensate fluid components, condensate will safely be led away from VCD by this connection. A tube to a floor drain should be connected here.

2.1.2.7 Condensate Output (11L3-04,12). Most generally a tube leading to a collection beaker is used here. If unattended for long periods, make sure overflow is led to a floor drain.

2.2 Energizing Procedure.

2.2.1 Mechanical. The following steps are to be taken to place the VCD in operation.

1. Fill recycle tank with distilled water and replace filter.
2. Insure all MDV's open. The wrench flat on Hamilton Standard MDV's and the screwdriver slot on LMSC MDV's indicate the flow path.
3. Pressurize waste tank to 5 psig.
4. Input about 5 lb. waste stock from either a pressurized tank, or a transfer pump. Be careful to not overpressurize bellows. Bellows may take 15 psid either direction.

2.2.2 Electrical. (Make sure 2.2.1 Accomplished First.)

1. Insure all connectors connected in the module and all power connections made, including those to the display panel.
2. Disconnect Main Power Cable P9 on the module.
3. Disconnect motor power cable P110.
4. Energize 400 Hz, AC and 29.5 VDC power supplies.
5. Insure proper voltages and phase relationships exist at P9.
6. Connect P9.
7. Turn on display panel power.

8. Turn controller RUN/DRYDOWN switch to DRYDOWN.

9. Observe operating mode light DRYDOWN, and drydown cause light MANUAL DRYDOWN.

10. If any other drydown cause lights are on other than CONDENSER PRESSURE HIGH, take appropriate action to correct the improper physical parameter condition.

11. Erase obsolete drydown cause lights by momentarily interrupting display panel power.

12. Slowly disengage Δ P sensor plug P107.

13. Observe ΔP meter momentarily go full scale and STOP mode come on.

14. Connect P110.

15. Turn controller RUN/DRYDOWN switch to RUN.

16. Erase obsolete drydown cause light MANUAL DRYDOWN by method of step 11.

3.0 Operating Procedure. After completing the above steps of setup and energizing, the following steps should be taken to operate the VCD.

3.1 STARTUP

1. Add more waste.
2. Observe waste quantity exceed 22%.
3. Observe STARTUP mode light.
4. Observe Purge Pump on.
5. Observe Condenser Pressure Decline.

3.2 RUN

1. When condenser pressure less than 40 torr observe Still motor and liquids pump motors on.
2. Observe Centrifuge Speed increase from zero.
3. When centriguge speed exceeds 200 RPM, observe feed shutoff valve (C/N 21) in open position.
4. Observe diverter valve (C/N 54) in non-divert position.
5. Observe recycle valve (C/N 15) in waste position.
6. Observe RUN mode.

3.3 DIVERT. After establishment of RUN, if ever conductivity on two or more of the sensors exceeds 50μmho cm^{-1}, or if the boiler temperature exceeds $37.8^{o}C$ ($100^{o}F$), observe DIVERT. The diverter valve (C/N 54) will be placed in the divert position until the upset condition is corrected.

When two or more of the conductivity sensors decline below 40μmho cm^{-1} and the boiler temperature declines below $32.2^{o}C$ ($90^{o}F$), observe RUN. Observe diverter valve placed in non-divert position.

3.4 DRYDOWN. 1. If any of the following conditions are observed, DRYDOWN will result.

a. Waste quantity below 2%
b. Condenser Pressure above 40 torr
c. Liquid level high continuously for 5-6 sec.
d. Waste tank pressure low.
e. Controller RUN/DRYDOWN switch to DRYDOWN.

2. Observe shutoff valve placed in shut position.
3. Observe diverter valve placed in divert position.
4. Recycle valve is placed in recycle position when waste quantity declines below 15% and may or may not be placed thus at this point.
5. Observe compressor ΔP rise.

3.5 STOP.

1. When compressor Δ P exceeds 15 mmHg observe STOP.
2. Observe purge pump, liquids pump and still motors off.

4.0 Data Management. A sample data sheet and VCD Parameter Abbreviations list are included. The exact method of instrumentation and recording rests with the experimenter. A data connector (J11) is provided on the back of the display panel. Refer to drawing BE 11908 for pin assignments. Other data are obtained either from the display panel or collateral instrumentation.

4.1 Calibration. VCD will operate with display panel disconnected. Controller logic sensor inputs are monitored internally. Thresholds are established by sensor calibration. Once thresholds have been calibrated, the displays are adjusted by display buffering circuit adjustments to provide proper zeroing and ranging. Therefore, the calibration procedure should follow these steps:

1. Apply physical parameter to known level.
2. Observe controller logic change of status.
3. If logic change of state needs change, accomplish same internal to controller by adjustment of circuit values.
4. With parameter at known zero point, adjust display to zero. Apply parameter change.
5. Observe display and adjust range control until in agreement with parameter.

4.2 Data Sources. Data is obtained from the following sources.

Parameter	Source
CDP	Display panel
CM1,2,3	Display panel (select switch chooses which displayed)
COB	Collection beaker + graduated cylinder
COM	Display panel (manually reset for each run)
CT	Cold trap + graduated cylinder
DC	Display panel
DDC	Display panel
IA, IB, IC	400 Hz power supply
IDC	DC power supply
LLS	Display panel
MAN	Display panel
NX	Display panel
PB	Lab. barometer
PC1	Display panel
PC2	Supplemental pressure gage
PF	Display panel
PLP, PPP	Supplemental polyphase wattmeter
t	Lab clock
tC	Display panel
tD	Display panel
tR	Display panel
TC1,2,3,4, TDS, TM	Supplemental temperature instrumentation
TCE	Copper Constantan T/C installed in still on spare connector below speed sensor. Pin B Constantan Pin C Copper

Parameter	Source
TE1, TE2	Display panel (Controller switch chooses which displayed)
VA, VB, VC	400 Hz Power supply or handheld VOM
VDC	DC Power supply or handheld VOM
W1	Display panel
W2	Platform scale

4.3 Data Frequency. The frequency of data taking is left to the experimenter. The sample data sheet is set up for hourly readings. Certain events such as mode changes should be recorded when they occur. Short term transient events require a more frequent sampling.

Determination of solids and pH values require extraction of recycle liquor from a collateral tap. The experimenter should be cautioned to not make large extractions to avoid undue dilution of solids ratios attained.

5.0 Preparation for Storage

When placing VCD in prolonged storage perform the following with VCD stopped.

1. Drain waste tank with pressurant on.
2. Remove, drain, and flush recycle tank.
3. Refill and reinstall recycle tank.
4. Break feed plumbing between (C/N 22) and (C/N 23). Break recycle plumbing between (C/N 40) and (C/N 42). Install connections to clean pressure regulated water source set to 10 psig max.
5. Flush out feed and recycle plumbing by manipulating recycle valve (C/N 15) manually.
6. Reconnect feed and recycle plumbing.
7. Operate VCD with distilled water waste stock for several hours.
8. Shut off VCD.
9. Dry still by prolonged purging with simultaneous application of external heat.
10. Disconnect all mechanical interfaces and cap off.

VCD RUN NO.________ CONFIGURATION NO.____ DATE__________

t	CDP	CM1	COB	COM	TCE	T1	T2	IDC	NX	PC1	tD	tR	TE1	TM	TROOM	W1	REMARKS

SAMPLE DATA SHEET

CM2	DDC	PLP	VA	IA
CM3	ND	PPP	VB	IB
CT	PB	tC	VC	IC
DC	PC2	TE2	W2	VDC

VCD PARAMETER ABBREVIATIONS

CDP = COMPRESSOR HEAD RISE (mmHg)

CM1 = CONDENSATE CONDUCTIVITY, SENSOR NO. 1 (MICROMHO PER CM)
CM2 = CONDENSATE CONDUCTIVITY, SENSOR NO. 2 (MICROMHO PER CM)
CM3 = CONDENSATE CONDUCTIVITY, SENSOR NO. 3 (MICROMHO PER CM)
COB = INCREMENTAL CONDENSATE QUANTITY BY BEAKER (CC)
COM = CUMULATIVE CONDENSATE QUANTITY BY METER (CC)
CT = INCREMENTAL CONDENSATE QUANTITY FROM COLD TRAP (CC)

DC = CAUSE OF LAST DIVERT (TE1 OR CM)
DDC = DRYDOWN CAUSE (W1, PC1, LLS, PF, MAN)

IA = 400 HZ, 208V, 3 PHASE CURRENT IN PHASE A (AMP)
IB = 400 HZ, 208V, 3 PHASE CURRENT IN PHASE B (AMP)
IC = 400 HZ, 208V, 3 PHASE CURRENT IN PHASE C (AMP)
IDC = DIRECT CURRENT TO STILL DRIVE MOTOR (AMP)

LLS = LIQUID LEVEL SENSOR ACTUATED MORE THAN 5 SEC

MAN = MANUAL

ND = NUMBER OF DIVERTS SINCE LAST OVERRIDE (N)
NX = CENTRIFUGE SPEED (RPM)

PB = BAROMETRIC PRESSURE (IN. Hg, ABS)
PC1 = CONDENSER PRESSURE (TORR)
PC2 = CONDENSER PRESSURE (IN. Hg, VAC)
PF = WASTE TANK FLUID PRESSURE LESS THAN 1.5 PSIG
PLP = POLYPHASE POWER TO LIQUIDS PUMP (WATT)
PPP = POLYPHASE POWER TO PURGE PUMP (WATT)

t = LOCAL CLOCK TIME (XXYY, XX=HR, YY=MIN)
tC = CUMULATIVE TIME ON SYSTEM IN RUN MODE (HR)
tD = CUMULATIVE TIME IN DIVERSION MODE THIS RUN (HR)
tR = CUMULATIVE TIME THIS RUN IN RUN MODE (HR)

TC1 = TEMPERATURE OF VCD OUTER SHELL POSITION 1 (^{o}F)
TC2 = TEMPERATURE OF VCD OUTER SHELL POSITION 2 (^{o}F)
TC3 = TEMPERATURE OF VCD OUTER SHELL POSITION 3 (^{o}F)
TC4 = TEMPERATURE OF VCD OUTER SHELL POSITION 4 (^{o}F)
TCE = TEMPERATURE COMPRESSOR EXHAUST (^{o}F)
TDS = TEMPERATURE OF DESUPERHEATER (^{o}F)
TE1 = EVAPORATOR (BOILER) TEMPERATURE, SENSOR 1 (^{o}C)
TE2 = EVAPORATOR (BOILER) TEMPERATURE, SENSOR 2 (^{o}C)
TM = TEMPERATURE DRIVE MOTOR CASE (^{o}F)

VA = 400 HZ, 3 PHASE LINE TO LINE VOLTAGE PHASE A TO PHASE B (VOLT)
VB = 400 HZ, 3 PHASE LINE TO LINE VOLTAGE PHASE B TO PHASE C (VOLT)
VC = 400 HZ, 3 PHASE LINE TO LINE VOLTAGE PHASE C TO PHASE A (VOLT)
VDC = DIRECT CURRENT VOLTAGE TO STILL DRIVE MOTOR (VOLT)

W1 = WASTE TANK LEVEL (% FULL)
W2 = WASTE INPUT TO WASTE TANK (LB)

Appendix B

Proposed Nuclear Gaging System for Vapor Compression Distillation System Waste Tank

This document describes a nuclear gaging system proposed for use on the VCD system waste tank. It is fully developed and will reliably give continuous waste quantity measurements with an accuracy greater than $\pm$ 3%. Emissions from the radiation source are well within acceptable dose requirements, and the source is heavily encapsulated to protect against accidents. The sections which follow present a description of the gaging system, and an analysis of its radiation safety aspects.

Gaging System Description

The proposed nuclear gaging system is manufactured by the General Nucleonics Division of Tyco laboratories. It is a fully developed piece of hardware, and an essentially identical system is used on the LMSC P-50 Program as a hydrazine propellant gaging system. The system also has been used successfully on aircraft oil gaging systems in over three thousand aircraft.

The system is a mass gaging system and the measurement is therefore independent of liquid density changes due to temperature or aeration of the fluid. The system will utilize a double encapsulated 1-1.7 millicurie cesium-137 source to emit gamma radiation. This source is a solid and could not be released into a spacecraft cabin atmosphere. Also, the double encapsulation protects it against most forseeable disasters. Sources of this type are used in many industrial thickness gaging systems.

As shown in Figure 1, the source will be placed on the bottom of the waste water tank, and the water will therefore always provide shielding. On the top of the tank, a detector tube picks up the radiation. Water in the tank reduces the count in proportion to the amount of water in the tank. The signal is then passed through a buffer and rate integrator, and is amplified to drive a quantity meter. The unit merely attaches to the tank and a standard tank of most any shape can be used. The unit consumes less than 3 watts of power, and a flight version would weigh less than 3 pounds. Performance parameters are summarized in Table 1.

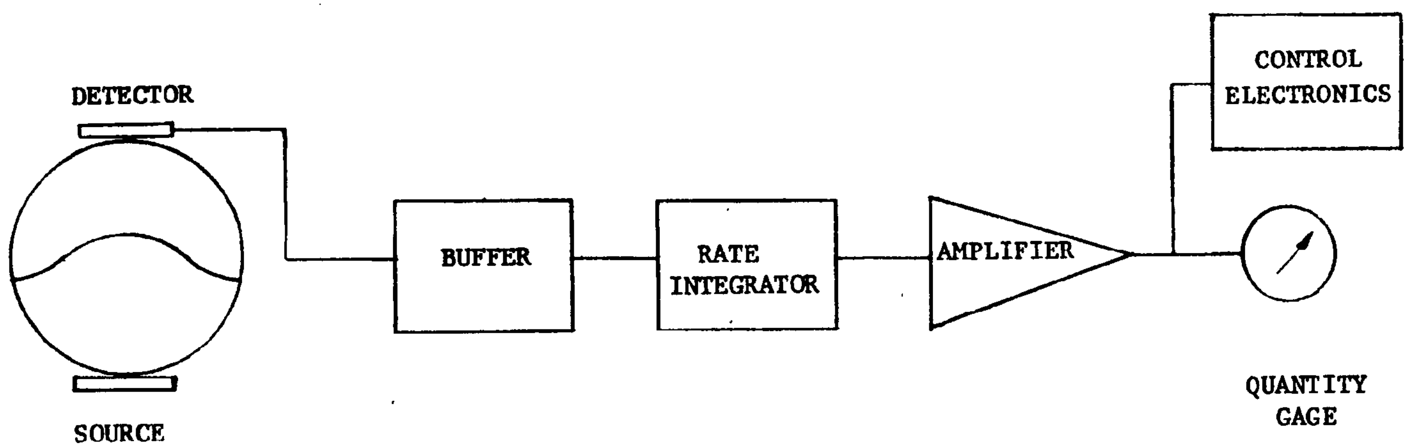


Figure 1 System Schematic

Table 1 Performance Summary

- o Accuracy - $\pm$ .3% when empty
  $\pm$ 3% when full
- o Continuous readout of quantity
- o Weight - 3 lbs.
- o Power - 3 watts max.
- o Radiation source - Cesium-137 sealed in glass
- o Source strength - 1-1.7 millicurie
- o Source half life - 27 years
- o Will not make water radioactive
- o Radiation dose at 3 ft. distance approximately .06 millirad/hr (tank half full)
- o Continuous exposure dose at 3 ft. = 128 millirad per 3 mo. versus allowable of 1250 millirad per 3 months.

The radiation source is solid cesium-137 as compared to the P-50 Program krypton-85 gas source. The solid source cannot be released to the spacecraft cabin atmosphere. In addition, it would be double encapsulated in stainless steel. Use of this source would not alter the operation of the existing gaging system and would not require any new development. The source is a cylinder, about ½ in. diameter by 3/8 in. long.

The detector assembly is a commercially developed Geiger tube. It has proven reliable in both commercial and airborne applications. It is approximately ½ inch in diameter and 7 inches long.

The electronics consists of a power supply, buffers, rate integrators and amplifiers. It is a commercial version of the P-50 electronics, and operates on 120 VAC 60/400 Hz. Both a meter quantity indication and 0-1 V output is provided. The output is proportional to the quantity of liquid in the tank, but is slightly non linear. Adjustments are provided for full and empty calibrations.

In operation, radiation from the source is detected by the detector tube which provides output pulses. Liquid in the tank attenuates the pulse rate and the output is therefore proportional to the amount of water in the tank. The output of the detector is fed to a buffer where the pulses are squared. They are then fed to an integrator where the pulse rate is converted to an analog DC signal proportional to the pulse rate. This signal is amplified to drive a meter and to provide a 0-1 VDC output. The 0-1 V signal can be used, in conjunction with other control electronics, to control starting and stopping of the Vapor Compression Distillation unit.

Radiation Safety Aspects

The radiation source for the tank level gage is cesium-137, sealed in glass. From 1 to 1.7 millicurie of radioisotope are used. Cesium-137 decays, with a 27 year half-life, to barium. It emits a 0.67 Mev gamma ray. The source is encapsulated inside a welded stainless steel capsule. This capsule is in turn sealed inside a larger similar welded stainless steel capsule. Such sources have passed the vigorous test program of the American National Standards Institute for resistance to temperature, pressure, impact, vibration and puncture, listed in Table 2. The technique of double encapsulation has been used for many years in fabrication of safe sources. There is no pressure build up in cesium sources as the decay product is a stable metal atom, unlike the situation with plutonium-238 radioisotope heat sources. The cesium source operates at ambient temperature as the internal power dissipation is negligible.

Radiation from the source is 3.2 millirad/hr at 1 foot for a 1 millicurie source. It consists of the 0.67 Mev gamma ray. Such radiation does not activate other materials. The source will be located at the bottom apex of the spherical waste tank. Radiation reaching personnel must traverse the tank wall twice, plus the diaphragm, plus the tank contents. The attenuation in traversing 7½ in. of water (the average amount present) plus 1/8 in. of iron is calculated to reduce radiation intensity by a factor of 6. For a three foot average separation distance between the source and personnel, an additional attenuation of a factor of 9 is obtained. Dose received at this point is thus 0.059 millirad/hour. If personnel stay at this location continuously for 3 months, they would receive 128 millirad.

The allowable dose for radiation controlled personnel exposure is 1250 millirad per 3 month interval. Thus the radioisotope tank level gage is a safe device.

It is of interest to point out that Lockheed Missiles and Space Company holds Nuclear Regulator Commission License 04-01964-08, under which up to 10 millicuries of sealed sources such as cesium-137 may be in possession. The

Biotechnology department recently completed tests of an isotope heated catalytic oxidizer in which a multicurie plutonium 238 heat source was used, which operates at about 900°F. There were no radiation incidents.

Table 2   Source Integrity Tests

The source shows no leakage of the radioisotope after the following tests:

Temperature: Cycle from 927°C to 15°C by plunging into cold water.

External Pressure: 3.4 to 1000 psia pressure conditions

Impact Resistance: Drop 20 lb. weight from 5 ft. onto source

Vibration: Prescribed conditions including: 30 minutes at 25-50 cps at 5g; 50-500 cps at 10 g peak-to-peak

Puncture: Drop source 10 ft. onto 1/8 inch diameter pin

Source classification: 54434 (most vigorous tests in all categories)

Specification: American National Standards Institute
ANSI USA SIC N54

Supplier: Amersham-Searle Corporation, Illinois

APPENDIX C

COMPUTER STUDY OF ALTERNATE MEANS OF INCREASING VAPOR COMPRESSION DISTILLATION SYSTEM PROCESS RATE

FEBRUARY 1, 1977

Prepared Under Contract NAS 9-15136

by

Biotechnology

Lockheed Missiles & Space Company, Inc.
Sunnyvale, California

for

National Aeronautics & Space Administration
Johnson Space Center

1.0 Summary

A computerized analysis of the operation of the VCD system was conducted to optimize the handling of input waste water. The study showed that by adding a single three way valve and altering the controls to permit recycle of the waste water tank at the beginning of each daily operating period, a savings of 14% on both equipment weight and power are possible. The savings result from increased average and last day process rates made possible by recycling the daily fresh wastes which have a low solids content. The cost and reliability impact of implementing the optimized operating mode should not be significant penalties. In the following sections, the current (baseline) system and candidate alternates are compared and the results of the analysis are discussed. The computer program and the run data sheets are presented in section 4.

2.0 System Requirements and Candidate Concepts

In the analysis, three general process concepts were evaluated.

A. Baseline system

B. Baseline system with modified valving and controls

C. Concept 2 plus a separate waste water accumulator

Concepts B and C also were studied with both a fixed volume and variable volume recycle tank. The variable volume recycle tank allows the dry down waste, at the end of each day, to be stored in the recycle tank rather than the waste water tank. This design approach further reduces the concentration of solids processed by the VCD system on a time averaged basis.

In order to establish a common basis for comparison, the following requirements were established.

Recycle Tank	30 day change out
Urine generation	19.9 lbs/day
Flush water usage	12.0 lbs/day
Pretreatment Chemical	0.1 lbs/day
Waste water solids	0.02756 lb/lb water
Emergency storage	1 day
Operation time	16 hrs/day maximum

In addition a model micturation profile was developed for the study based on the SSP specifications, which suggests design to 42 micturations per day. Figure 1 presents the micturation profile used for the study and Figure 2 shows the daily cumulative micturations. The profile is important to definition of system control points as described later. A design requirement of start up of the system on the first mission day was also established. This provides the minimum impact to the potable water stores as the output of the VCD will be immediately available for use.

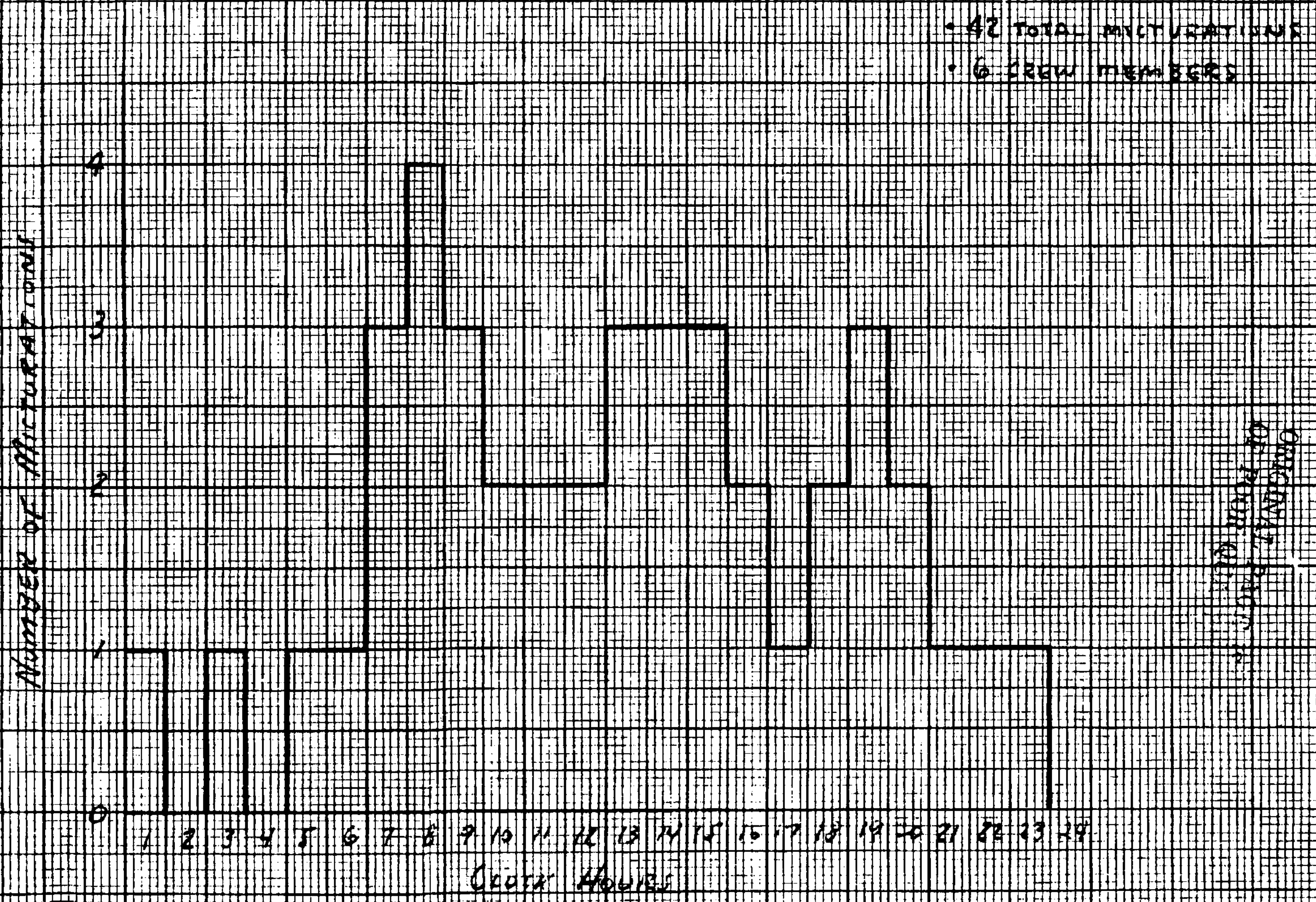
Weight and power penalties for the other design approaches were derived by rationing the following baseline system values:

Compressor Power	85 watts
Liquid Pump Power	25 watts
Control Power	15 watts
Purge Pump Power	40 watts
Recycle Tank Weight Penalty	0.51 lb tank/lb liquid
Waste Water Tank Weight Penalty	1 lb tank/lb liquid
System weight (less tanks)	201 lbs.

2.1 Baseline System

A schematic diagram of the waste water loop for the baseline VCD system is shown by Figure 3. In the operation of the system, there are two waste water tanks; the recycle tank and the waste water tank. In the current operating mode, waste is drawn from the recycle tank and pumped into the still at a rate greater than the process rate. The excess after the condensate is removed, is returned to the recycle tank. Make up waste water, in quantity equal to the amount of distilate removed, is supplied to the recycle loop from the waste water tank. Thus, the recycle tank remains

FIGURE 1 DAILY MICTURATION SCHEDULE



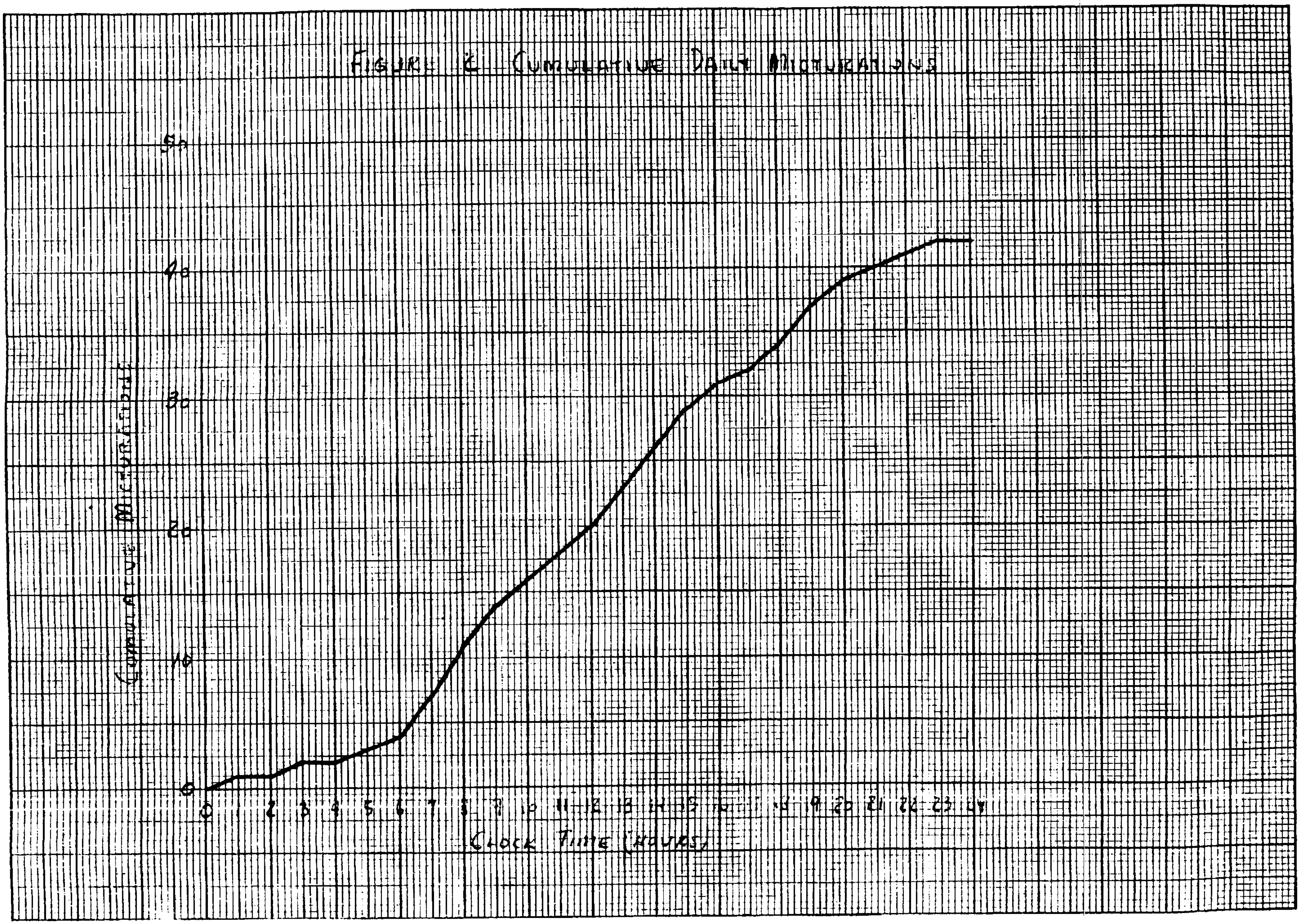
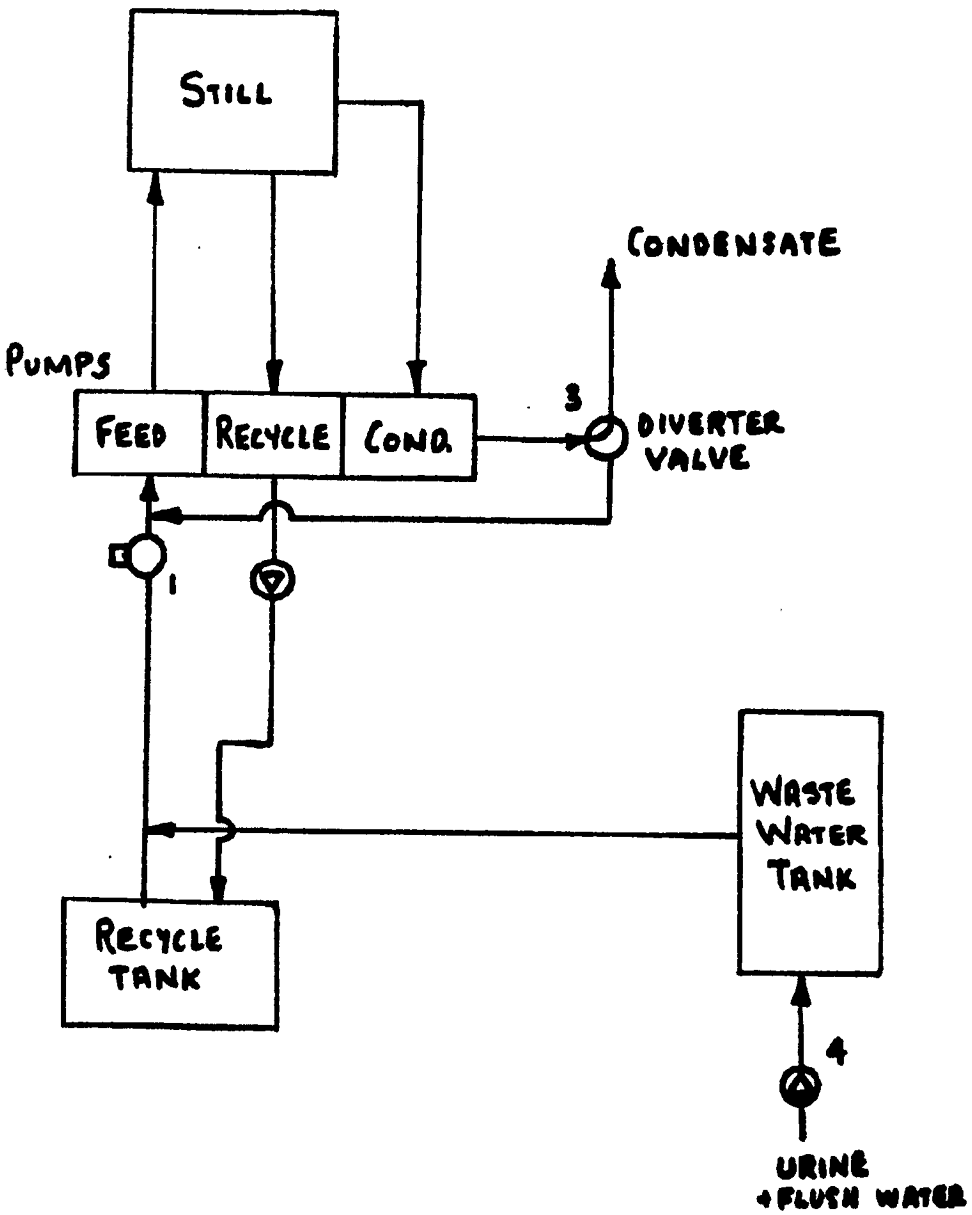


FIGURE 2 CUMULATIVE DAILY MICTURATIONS
CUMULATIVE MICTURATIONS
0
10
20
30
40
50
0 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 20 21 22 23 24
CLOCK TIME (HOURS)

Figure 3 Baseline System Schematic



Valve	Mode 1	Mode 2	Drydown
1	Open	N/A	Closed
2	N/A	N/A	N/A
3	Storage	N/A	Recycle
4	N/A	N/A	N/A

full at all times. The size of the recycle tank is set by a final solids concentration of 50% after 30 days of operation. After 30 days of operation, it is removed and a new tank, full of fresh water, is placed in the system. The size of the waste water tank is defined by the requirements to store the differences between waste water production and waste water processing plus an accumulation of 24 hours of waste water in the event of a major failure. In normal operation, the system is operated for less than 24 hours per day. Each day, the system is started when the waste water tank contains 10 pounds of wastes. New waste water enters the system at a rate slightly less than the process rate, so therefore, after 16 hours of operation, the waste water tank volume will drop to 0.8 pounds activating a dry down signal. The actual selection of starting volume and shutdown signals is sensitive to the micturation schedule as discussed later in Section 3.0. During the drydown, about 1.25 pounds of waste material in the boiler and lines is pumped into the waste water tank. During the system shutdown period that follows drydown the waste water tank provides the storage for the dry down wastes and new accumulations of waste water.

During system operation, as the solids concentration builds in the recycle tank, the process rate decreases as shown in Figure 4. If the process rates of Figure 4 are non-dimensionalized by dividing the values by the maximum process rate, it can be seen that the process rate will vary from unity on the first day of operation of a new recycle tank, to a low of .546 when the solids concentration reaches 50%. As a result the daily operating time will be quite variable and the system size is determined by the lowest daily process rate.

It was the purpose of this study to explore alternate operating modes which will increase both the average and final day process rates. Referring to Figure 4, it can be seen that processing the fresh waste at the lowest possible concentration results in the maximum process rate. The current process scheme always processes waste at the highest possible concentration, mainly that of the recycle tank. No advantage is taken of the fact that fresh, 2% solids, waste is collected each day.

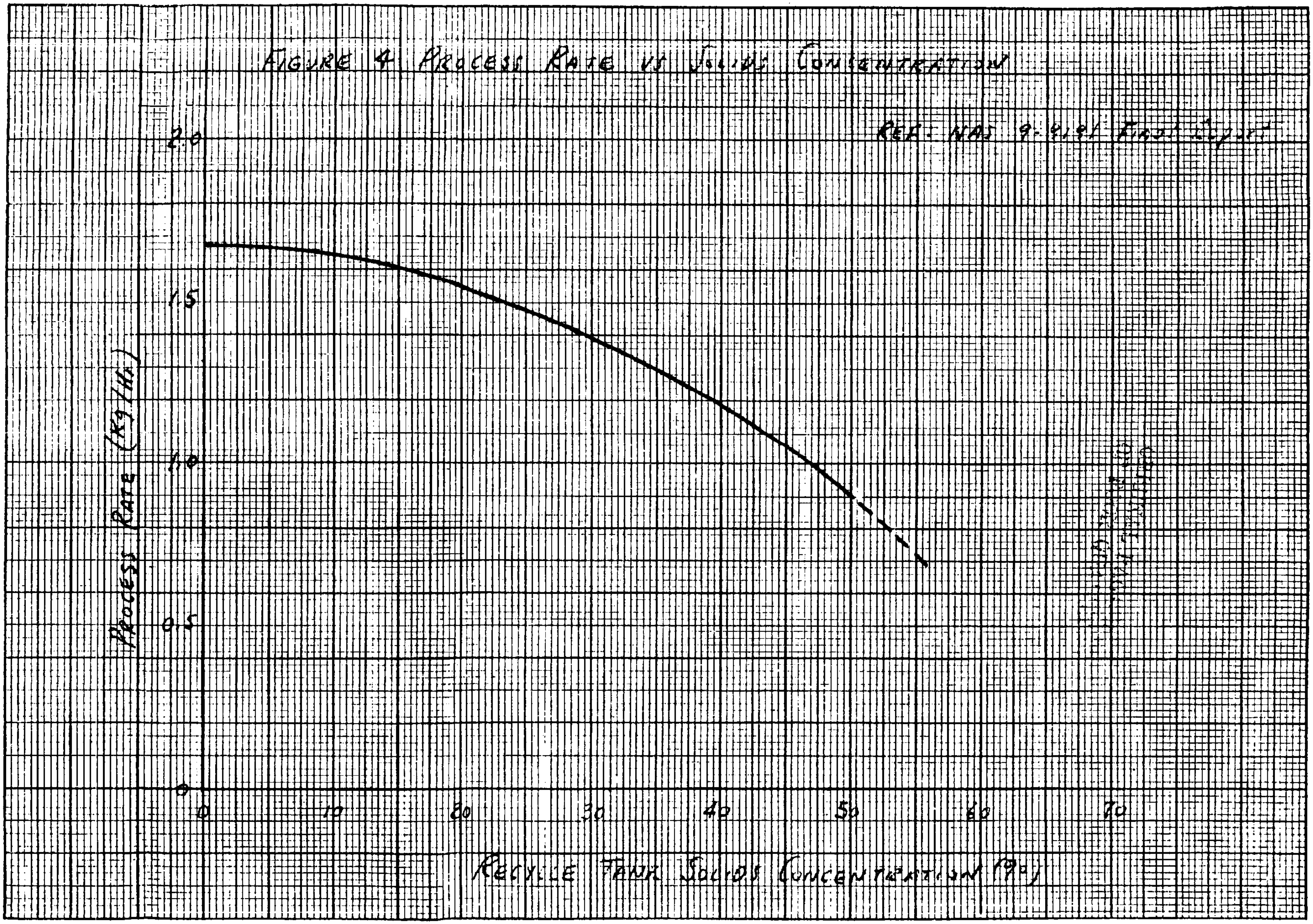


FIGURE 4 PROCESS RATE VS SOLIDS CONCENTRATION
REF: NAS 9-4191 First Report
PROCESS RATE (Kg/Hr)
2.0
1.5
1.0
0.5
0
0
10
20
30
40
50
60
70
RECYCLE TANK SOLIDS CONCENTRATION (%)

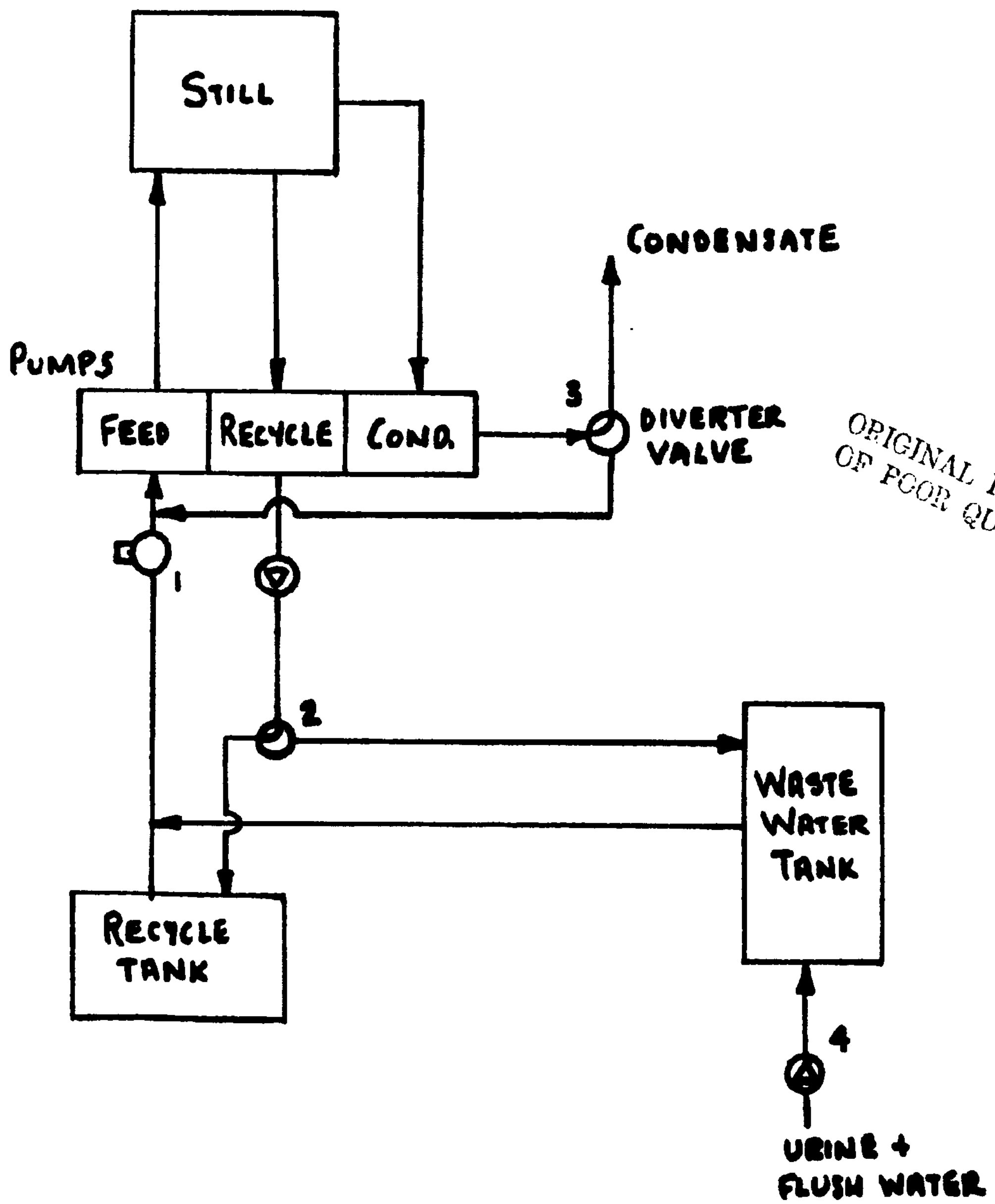
2.2 Concept A

One alternate to the baseline system which results in processing of the most dilute waste, is shown by Figure 5. For concept A, ~~once the system is~~ started up, recycle water is drawn from and returned to the waste water tank, instead of to and from the recycle tank as in the baseline system. Each day the processed water starts at a low solids content, thereby providing the highest possible water production rate. A system start uppoint, based on waste water tank quantity, is selected. The solids content in the waste water tank is allowed to build up, as distillate is removed in the boiler. At some elevated concentration of wastes in the waste tank, the system is switched to the normal operating mode using the recycle tank.

An analysis of concept A indicates that the optimum solid concentration in the waste tank at the switch point can vary in a wide range from 15 to 25 percent. If solids concentrations are below 20 percent there should be no fouling of the waste water tank. Above this level there may be some scaling of surfaces which would progressively reduce its volume and interfere with the operation of the bellows. Because solids concentration is difficult to measure, waste tank volume was selected as an indicator of switch point solids concentration. The switch volume is based on a last day analysis because maximum solids concentrations exist on that day. When the switch volume is reached, operation of the system is identical to that of the baseline system. Drydown will occur when the waste tank volume drops to the 0.8 lb level. The switching of operating mode is achieved by activation of a 3-way valve which must be added to the system.

As the mission progresses, the initial solids concentration, and as a result, final and average concentrations in the waste tank will increase. This is a result of the dry down waste water being returned to the waste water tank. One possible alternative is to modify the recycle water tank, so that the dry down water can be stored in it. This could be accomplished by making this tank "breathable" with a bellows or bladder. If this is done, the switch point and system penalty can be reduced.

FIGURE 5 CONCEPT A SYSTEM SCHEMATIC



VALVE	MODE 1	MODE 2	DRYDOWN
1	OPEN	OPEN	CLOSED
2	WASTE	RECYCLE	WASTE
3	STORAGE	STORAGE	RECYCLE
4	N/A	N/A	N/A

2.3 Concept B

Both the baseline system and Concept A designs are dependent upon the selected micturation schedule. The system start and stop waste tank quantities should be as close as possible to avoid unnecessary waste tank volume. If the micturation schedule is not as planned, it may be possible to cycle the system on and off several times wasting process time and power and decreasing overall reliability. One method of saving an unnecessary shutdown, would be to recycle condensate, if the shutdown is reached before the prescribed operating time but this is wasteful of power.

System Concept B, shown in Figure 6, provides for a separate accumulator tank which has a capacity of a full days supply of urine. The waste water tank is also sized to provide for a single day's storage. In operation, the contents of the accumulator are transferred to the waste water tank, at the start of the day's operation. The accumulator is then isolated from the rest of the system and collects another day's supply of waste water. The operation of system after isolation is identical to that of Concept A. The use of a breathable recycle tank also provides further advantages.

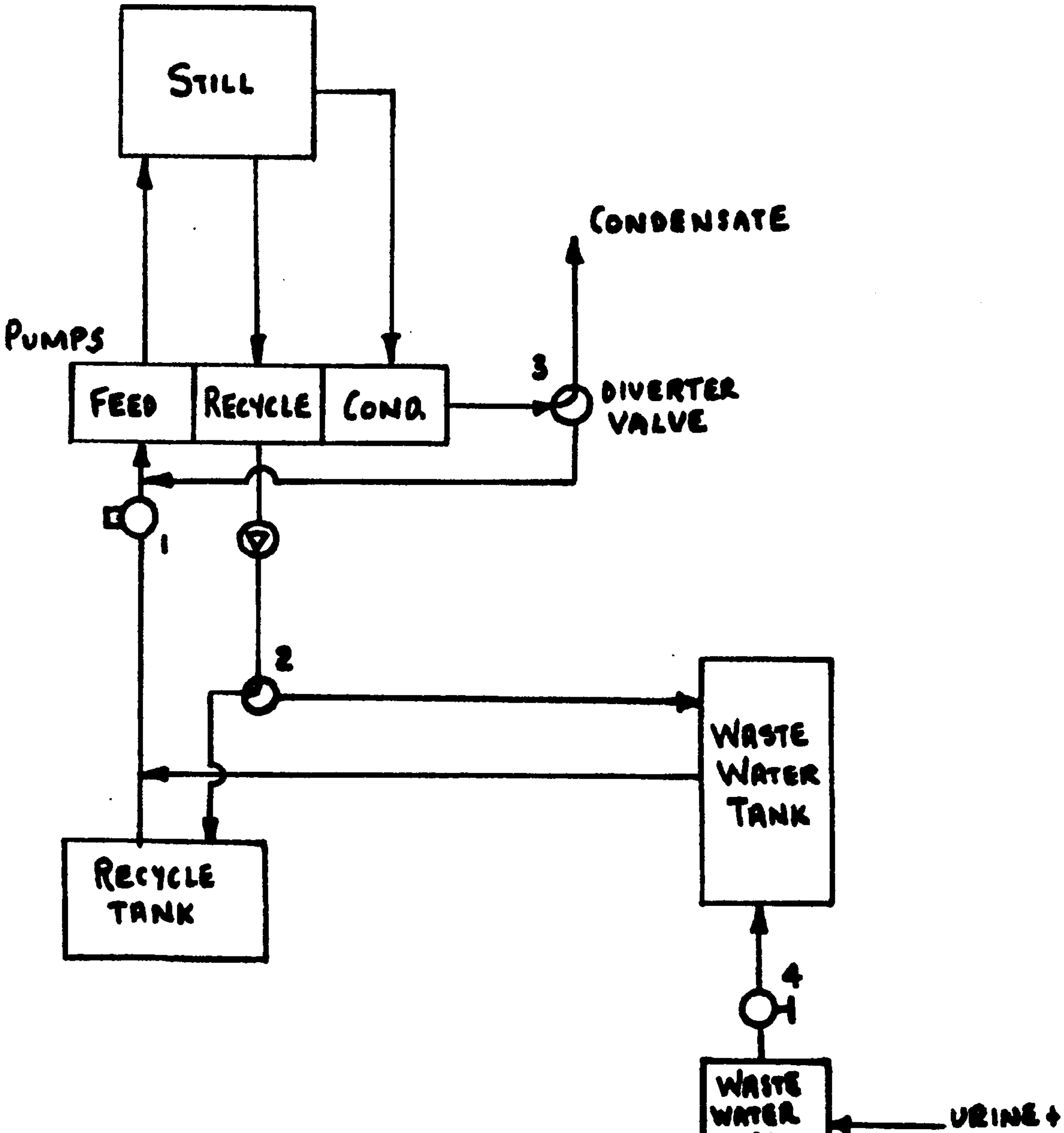
During the 16 hours of daily operation, new urine is stored in the accumulator. At the end of the 16 hour period, after completion of dry down, the isolation valve is opened and the contents of the accumulator are transferred directly to the waste water tank.

The primary advantage of this concept is that it makes the process independent of the micturation schedule. It does carry additional equipment and weight penalties.

3.0 System Analysis Methods & Results

In order to evaluate these concepts a computer program identified as @ TANK 2A was developed. A listing of the program, along with a list of variables is presented, in Section 4. The program consists of two main parts.

FIGURE 6 CONCEPT B SYSTEM SCHEMATIC



VALVE	MODE 1	MODE 2	DRYDOWN
1	OPEN	OPEN	CLOSED
2	WASTE	RECYCLE	WASTE
3	STORAGE	STORAGE	DIVERT
4	CLOSED	CLOSED	OPEN

- o Analysis of an inputed micturation schedule (Statements 60,000 - 70,160).
- o Analysis of the process rate for a given system concept (Statements 1000 - 10999).

Each major part makes use of the process rate vs solids data (statements 500 - 580) and the rate look-up routine (statements 50000 - 50060).

The selected micturation schedule (number for each of the 24 hours of the day) is input in 60060. The program then developes a matrix of time and micturation quantity. Table 1 is an output of this matrix for the micturation schedule used in the analysis based on a start time of 0900 hours. Because the inventory of waste water in the system will vary with system start time and initial start volume, the program first calculates the required start volume for each possible starting hour. The start volume must be sufficient to prevent a premature dry down signal from occuring at 0.8 lbs. Provisions are made to alter the number of hours the system operates per day (60260). Table 2 presents the program output for this analysis using a 16 hour operating day and the micturation schedule shown in Table 1.

The last section of this part of the program calculates an average process rate for some selected starting volume, starting solids content, and process time (statements 60200, 60210 and 70000 respectively). A material balance is carried out hourly to establish the total water, total solids content, and, as a result, solids concentration. The solids concentration is then used to set the process rate for the hour. The average rate is then calculated. Table 3 presents the results of this analysis. For this example, the average rate (R3) is shown printed out at the bottom of Table 3.

Table 1 Selected Micturation Schedule

Time of Day	Hours from Start	Micturation Quantity
9	1	2.28
10	2	1.52
11	3	1.52
12	4	1.52
13	5	2.28
14	6	2.28
15	7	2.28
16	8	1.52
17	9	0.76
18	10	1.52
19	11	2.28
20	12	1.52
21	13	0.76
22	14	0.76
23	15	0.76
24	16	0
1	17	0.76
2	18	0
3	19	0.76
4	20	0
5	21	0.76
6	22	0.76
7	23	2.
8	24	3.04

Table 2 Required System Start Quantity

Time of Start	Required Start Quantity to Prevent Shutdown During 16 Hr Run Period
Midnight	8.38
1	6.85
2	5.61
3	3.80
4	3.80
5	3.80
6	5.33
7	8.38
8	9.90
9	11.42
10	12.19
11	13.71
12	15.23
13	16.76
14	17.04
15	16.57
16	15.33
17	14.85
18	15.14
19	14.66
20	13.42
21	12.19
22	10.95
23	8.95

Table 3 Results for Concept A Analysis (0800 Hours Start)

Clock Time	Pounds of Waste in Waste Water Tank	Pounds of Salt in Waste Water Tank	Tank Solids Concentration (%)	% of Maximum Process Rate
0	13.38	0.51	3.83	0
8 (Startup)	13.66	0.57	4.21	99.3
9	13.18	0.61	4.68	99.1
10	12.71	0.65	5.18	99.0
11	12.23	0.70	5.73	98.8
12	12.52	0.76	6.10	98.7
13	12.80	0.82	6.46	98.6
14	13.09	0.89	6.80	98.5
15	12.61	0.93	7.39	98.3
16	11.38	0.95	8.38	98.0
17	10.90	0.99	9.13	97.7
18	11.18	1.05	9.46	97.6
19	10.71	1.10	10.27	97.3
20	9.47	1.12	11.83	96.7
21	8.23	1.14	13.87	95.4
22	6.99	1.16	16.62	93.7
23	4.99	1.16	23.27	88.9
24	5.76	1.18	20.56	0
1	5.76	1.18	20.56	0
2	6.52	1.20	18.48	0
3	6.52	1.20	18.48	0
4	7.28	1.22	16.83	0
5	8.04	1.24	15.50	0
6	10.33	1.31	12.68	0
7	13.38	1.39	10.42	0

Average Process Rate = 97.3

The second part of this program makes an analysis of Concept B. The analysis is broken into two parts. First, each day an average rate is calculated for recycle of water in the waste water tank. This is based on an input of some switch point. Then, the times for waste tank and recycle tank processing are calculated. The daily average rate is then calculated on the time weighted rates for each operating mode. This calculation is carried out for each day of the 30 day life of the recycle tank. Then, a mission average rate is calculated. In the calculations the following parameters are variable.

- o Number of days of baseline type operation before starting Concept B controls.
- o Drydown waste return to the waste water tank.
- o Waste water tank residual.

By setting the number of days for baseline operation at 30, baseline system performance is calculated. The results of the baseline analysis presented in section 4 show that the average and last day process rates are 0.812 and 0.546 respectively. Mat C is the process rate vs solids data. The next table shows by day; the waste tank initial and final solids weight, solid concentration, and process rate time.

Following the baseline system run, a number of runs were made to determine the effect of:

- o days of baseline operation
- o waste tank switch concentration
- o effect of drydown diversion to the recycle tank
- o effect of drydown diversion and elimination of waste water tank residual

C-3

These runs are presented in section 4. Figure 7 shows a plot of the results for starting modified operation on the first day, having a dry down residual of 1.25 lbs, and having a 0.8 residual in the waste water tank. This figure shows that a significant improvement in average and last rates can be achieved by the modified operation. It also shows that the highest practical switch concentration should be used. A switch concentration of 20 percent on the last day was selected, which should prevent fouling of the wastewater tank.

Considering the desired 20 percent last day switch point, computer runs were made for cases where:

- o Dry down was returned to the waste water tank - initial switch concentration = 12%
- o Dry down was returned to the recycle tank - initial switch concentration = 18%
- o Dry down was returned to the recycle tank and the waste water tank residual was eliminated - initial switch concentration = 20%.

In evaluation of concept A, it is observed that the average of the initial period (before switch) is about 1.5 percent higher if the tank starts full as in the program. The lower value results from the evaluation of the micturation schedule.

Setting the final day switch concentration at 20 percent, the weight and power data for each concept was developed. The results are presented in Table 4. Data for Concept A and B were scaled from the baseline weight and power data. Table 4 presents waste tank total capacity, system start capacity, mode switch capacity, mode switch concentration, average and last day process rates, and system power and weight estimates for each concept. The results of the analysis show a clear weight and power savings for Concept A. Concept B shows less savings, but has the advantage of eliminating dependency on micturation schedule. Modification of the recycle tank shows some additional minor weight and power savings. Based on the results of the study, it is recommended that Concept A, without modified recycle tank be selected for the VCD system design.

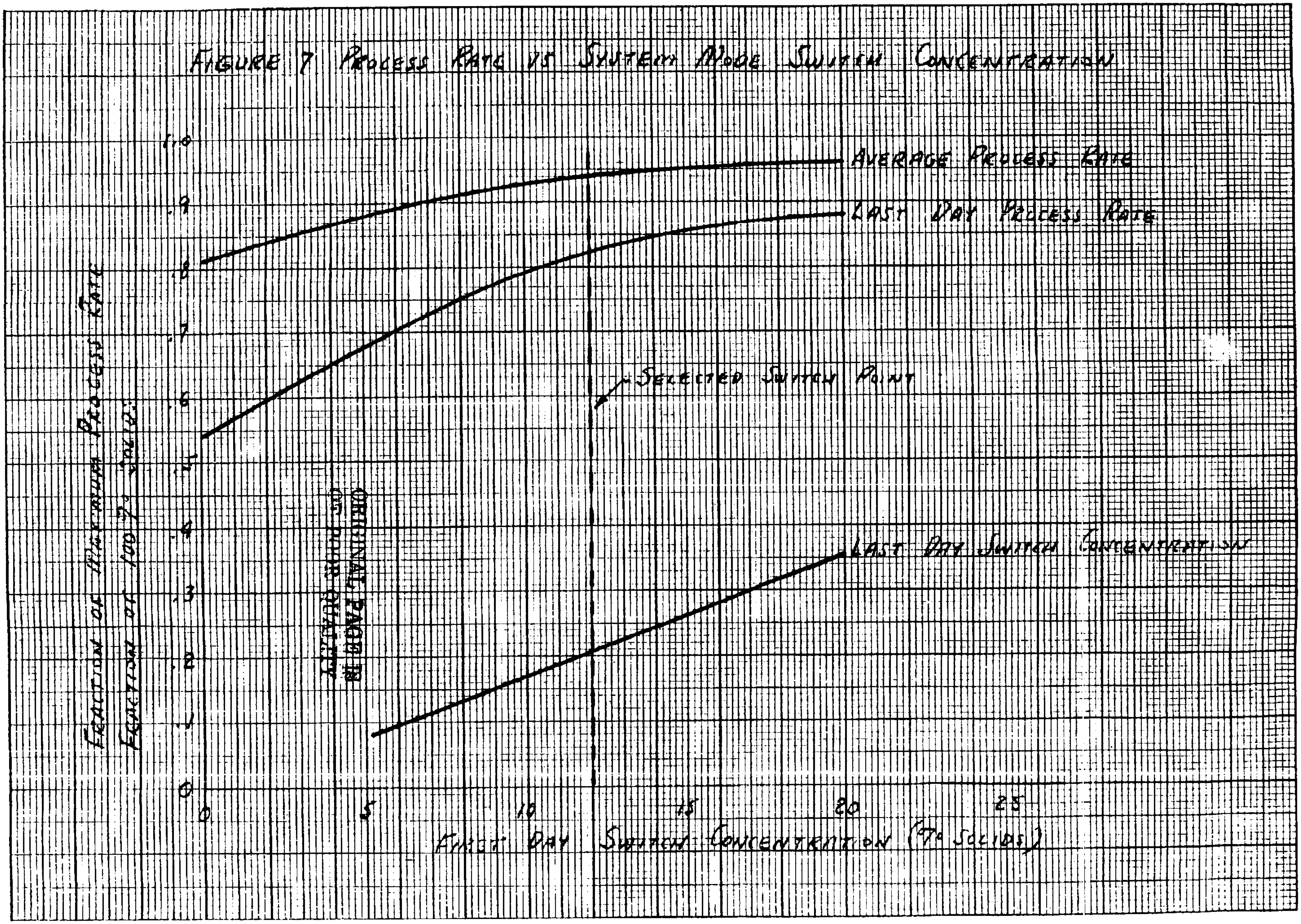


FIGURE 7 PROCESS RATE VS SYSTEM MODE SWITCH CONCENTRATION

Table 4 Candidate Concept Comparisons

Parameter	Baseline System	Concept A	Concept A with new recycle tank	Concept B	Concept B with new recycle tank
Waste Tank Capacity (lb)	42.1	42.1	40.8	34.1	32.8
Sys. Start Capacity (lb)	10.1	10.1	8.8	34.1	32.8
Mode Switch Capacity (lb)	-	8	5	8	5
Mode Switch Solids Concentration (%)	-	12-20.5	18-20.5	12-20.5	18-20.5
Ave Process Rate Ratio	0.812	0.925	0.930	0.94	0.955
Last Day Process Rate Ratio	0.546	0.810	0.860	0.826	0.875
System Sizing Factors					
Weight	1	.674	.635	.661	.624
Power	1	.877	.873	.864	.850
Power: (watts)					
Compressor	85	74.5	74.2	73.4	72.3
Liq. Pump	25	20.5	19.9	20.3	19.8
Controller	15	15	15	15	15
Purge Pump	40	32.8	31.9	32.5	31.6
*Total Power (watts)	165	142.8	141.0	141.2	138.7
Power Penalty (lb)	62.8	54.4	53.7	53.8	52.8
Fixed Weight (lb)	302.0	274.9	240.7	245.5	238.6
Waste Water Tank Wt (lb)	42.1	42.1	40.8	34.1	32.8
Recycle Tank Wt. (lb)	20.8	20.8	23.8	20.8	23.8
Stored Water Penalty (lb)	10.1	10.1	8.8	34.1	32.8
Valve Wt. (lb)	-	1.5	1.5	1.5	2.5
New Tank Wt. (lb)				28.0	28.0
*Total Weight (lb)	375.0	322.4	315.6	364.0	358.5
*Total Equiv. Wt. (lb)	437.8	376.8	369.3	417.8	411.3
*TEW Savings (lb)	0	61	68.4	20	26.4

*Most significant data for comparison.

Section 4.. Computer listings and output sheets.

4.1 Analysis Computer Program

@ TANK 2A

Slight modifications in residual and drydown result in programs @ TANK 2B and @ TANK 2C

See 2085

3012

3013

4084

SYSTEM: C9
FILE: @TANK2A   JANUARY 25, 1977 9:34 AM P

CHECKSUM: 74113733

```
500   !SOLIDS VS RATE DATA
501    MAT C = ZER(14,2)
510   FOR I = 1 TO 14
520   READ C(I,1)
530   NEXT I
540   FOR I = 1 TO 14
550   READ C(I,2)
555    C(I,1)=C(I,1)/100
560   NEXT I
570   DATA 0,4,8,12,16,20,24,28,32,36,40,44,48,52
580   DATA 1,.994,.982,.967,.941,.917,.884,.849,.801,.751,.7,.635,.564,.50

600 PAUSE
1000   !INPUT DATA
1010   PRINT "INPUT DAILY MATRIX INCREMENTS"
1020   I9=10
1030   PRINT "INPUT DAYS IN MODE 1"
1040   INPUT I8
1050   I7=30
1070   PRINT "INPUT SWITCH CONCENTRATION"
1080   INPUT C1
2000   !SET UP TO GO
2005   C3=.02756
2010   R=0
2020   R1=0
2050   MAT A= ZER(I9+1,5)
2060   MAT B= ZER(I7+1,6)
2080   B(1,1)=0
2085   V1=(32+1.25+.8)
```

```
2086   V2=V1*C3/C1
2087   T1=(32-V2)/32
2088   T2=V2/32
2090   C2=(I7/.5)*(32*.02756)
3000   !WASTE TANK CALCULATIONS
3010   FOR I = 1 TO I7
3011   R=0
3012   A1=((V1-1.25)-V2)/I9
3013   A(1,1)=(V1-1.25)
3015   FOR K = 1 TO I9
3020   A(K,2)=A(K,1)-A1
3030   A(K,3)=((2*V1*C3)/(A(K,1)+A(K,2)))
3035   D=A(K,3)
3040   GOSUB  50000          !GET RATE D9
3050   A(K,4)=D9
3060   A(K,5)=A1/A(K,4)
3070   R=R+A(K,5)
3080   A(K+1,1)=A(K,2)
3090   NEXT K
3095   R2=(I9*A1)/R
4000   !RECYCLE TANK CALCULATIONS
4010   FOR I = 1 TO I7
4020   B(I,2)=B(I,1)+.882
4030   B(I,3)=(B(I,1)+B(I,2))/(2*C2)
4035   D=B(I,3)
4040   GOSUB  50000          !GET RATE D9
4050   B(I,4)=D9
4060   IF I<(I8+1) THEN B(I,5)=1/B(I,4) ELSE B(I,5)=(T1/R2)+ (T2/B(I,4))
4070   R1=R1 + B(I,5)
```

```
4080  B(I+1,1)=B(I,2)
4084  C3=((.8*C1)+(1.25*(B(I,2)/C2))+(32*.02756))/V1
4085  B(I,6)=C3
4086  C3=B(I,6)*V1
4090  NEXT I
4095  R1=R1/I7
4096  R1=1/R1
10000 !OUTPUT
10001 PRINT FOR I = 1 TO 5
10005 PRINT C1,I8
10009 PRINT V2,(V1*B(I7,6)/A(I9,2))
10010 PRINT R2,R1,(1/B(I7,5))
10020 PRINT T1,T2,(T1+T2)
10030 IF C1<.31  THEN C1=C1+.05   ELSE  C1=.05 , I8=I8+5
10040 IF I8>15 THEN END
10050 GO TO 2000
10999 END
50000 !RATE LOOK UP SUBROUTINE
50010 FOR J = 1 TO 14
50020 IF D<C(J,1) THEN GO TO 50040
50030 NEXT J
50035 PRINT "OUT OF RANGE MAT C"
50036 STOP
50040 D1=C(J-1,1),D2=C(J,1),D3=C(J-1,2),D4=C(J,2)
50050 D9 = D3 - ((D3-D4)*((D-D1)/(D2-D1)))
50060 RETURN
60000    DIM E(24)
60010 MAT F = ZER(24,5)
60020 MAT G = ZER(25,5)
```

```
60025  R3=0
60030     S9=0
60040     S=8
60050     G(1,1)=0
60060    MAT READ E
60070    DATA 1,0,1,0,1,1,3,4,3,2,2,2,3,3,3,2,1,2,3,2,1,1,1,0
60080    FOR I = 1 TO 24
60090    S9=S9+E(I)
60100    NEXT I
60110    FOR I = 1 TO 24
60120    F(I,1)=I
60130    F(I,2)=E(I)
60140    F(I,3)=E(I)*32/S9
60150    NEXT I
60160    FOR I = 1 TO 24
60170    IF I+S<25 THEN F(I,4)=F(I+S,3)  ELSE F(I,4)=F(I-24+S,3)
60175  IF I<(25-S)  THEN F(I,5)=I+S   ELSE   F(I,5)=I-24+S
60180    NEXT I
60190    FOR I = 2
60200    G(1,I)=13.38
60210    G(1,3)=.51275
60220    G(1,4)=G(1,3)/G(1,2)
60230    FOR J = 2 TO 25
60240    IF J+S<27 THEN G(J,1)=J+S-2 ELSE G(J,1)=J-24+S-2
60250    G(J,I)=G(J-1,I)-(32/16)+F(J-1,4)
60260    IF J>17 THEN G(J,I)=G(J,I)+(32/16)
60270    G(J,3)=G(J-1,3)+(.02756*F(J-1,4))
60280    G(J,4)=G(J,3)/G(J,2)
60290    NEXT J
```

```
60300    NEXT I
70000  FOR I = 2 TO 17
70010  D=G(I,4)
70020  GOSUB 50000
70030  G(I,5)=D9
70040  R3=R3+G(I,5)
70050  NEXT I
70100  R3=R3/16
70110  PRINT FOR I = 1 TO 5
70120  PRINT R3
70130  PRINT
70140 MAT PRINT G
70150  PRINT FOR I = 1 TO 5
70160  MAT PRINT F
```

SYSTEM: C9
FILE: C9TANK2A

JANUARY 25, 1977 9:30 AM P*

CHECKSUM: 70032650

****

PROGRAM NAME IS: 9TANK2A

DICTIONARY OF VARIABLES WITH LINE REFERENCES

VAR.---REFERENCE LINE #

NAME

A1 3012 3020 3060 3095

C1 1030 2086 4084 10005 10030

C2 2090 4030 4084

C3 2005 2086 3030 4084 4085 4086

D 3035 4035 50020 50050 70010

D1 50040 50050

D2 50040 50050

D3 50040 50050

D4 50040 50050

D9 3050 4050 50050 70030

I 510 520 530 540 550 555 560 3010 4010 4020 4030
4035 4050 4060 4070 4080 4084 4085 4086 4090 10001
60080 60090 60100 60110 60120 60130 60140 60150
60160 60170 60175 60180 60190 60200 60250 60260

60300 70000 70010 70030 70040 70050 70110 70150

I7 1050 2060 2090 3010 4010 4095 10009 10010

I8 1040 4060 10005 10030 10040

I9 1020 2050 3012 3015 3095 10009

J 50010 50020 50030 50040 60230 60240 60250 60260

60270 60280 60290

K 3015 3020 3030 3035 3050 3060 3070 3080 3090

R 2010 3011 3070 3095

R1 2020 4070 4095 4096 10010

R2 3095 4060 10010

R3 60025 70040 70100 70120

S 60040 60170 60175 60240

S9 60030 60090 60140

T1 2087 4060 10020

T2 2088 4060 10020

V1 2085 2086 3012 3013 3030 4084 4086 10009

V2 2086 2087 2088 3012 10009

DICTIONARY OF ARRAYS WITH LINE REFERENCES

ARRAY---REFERENCE LINE #

A 2050 3013 3020 3030 3035 3050 3060 3070 3080 10009

B 2060 2080 4020 4030 4035 4050 4060 4070 4080 4084

4085 4086 10009 10010

C 501 520 550 555 50020 50040

E 60000 60060 60090 60130 60140

F 60010 60120 60130 60140 60170 60175 60250 60270

```
     70160
G    60020 60050 60200 60210 60220 60240 60250 60260
     60270 60280 70010 70030 70040 70140
```

CROSS REFERENCE OF LINE NUMBERS

LINE #	REFERENCE LINE #
2000	10050
50000	33040 34040 370020
50040	50020

◆◆

4.2 Output for Baseline System

Average Rate = .812

Last Day Rate =.546

MAT C - Data of solids fraction and fractional rate

MAT B - Output data

Solids initial, solids final, solids fraction, process rate, time fraction

Baseline

```
PRINT R1,(1/B(I7,5))
 .81215533         .5464331

>MAT PRINT C
 0                 1
 4E-02             .994
 8E-02             .982
 .12               .967
 .16               .941
 .2                .917
 .24               .884
 .28               .849
 .32               .801
 .36               .751
 .4                .7
 .44               .635
 .48               .564
 .52               .504

>
```

0	.882	8.3340893E-03	.99874989	1.0012517
.882	1.764	2.5002268E-02	.99624966	1.0037645
1.764	2.646	4.1670446E-02	.99349887	1.0065437
2.646	3.528	5.8338625E-02	.98849841	1.0116354
3.528	4.41	7.5006803E-02	.98349796	1.0167789
4.41	5.292	9.1674982E-02	.97762188	1.0228904
5.292	6.174	.10834316	.97137131	1.0294724
6.174	7.056	.12501134	.96374263	1.0376214
7.056	7.938	.14167952	.95290831	1.0494189
7.938	8.82	.1583477	.942074	1.0614877
8.82	9.702	.17501587	.93199048	1.0729723
9.702	10.584	.19168405	.92198957	1.084611
10.584	11.466	.20835223	.91010941	1.098769
11.466	12.348	.22502041	.89635816	1.1156255
12.348	13.23	.24168859	.88252249	1.1331156
13.23	14.112	.25835677	.86793783	1.1521563
14.112	14.994	.27502495	.85335317	1.1718478
14.994	15.876	.29169312	.83496825	1.1976503
15.876	16.758	.3083613	.81496644	1.2270444
16.758	17.64	.32502948	.79471315	1.2583157
17.64	18.522	.34169766	.77387793	1.2921935
18.522	19.404	.35836584	.7530427	1.3279459
19.404	20.286	.37503402	.73183163	1.3664345
20.286	21.168	.3917022	.7105797	1.4073017
21.168	22.05	.40837037	.68639814	1.4568804
22.05	22.932	.42503855	.65931235	1.5167318
22.932	23.814	.44170673	.63197055	1.5823522
23.814	24.696	.45837491	.60238454	1.6600692
24.696	25.578	.47504309	.57279852	1.7458146
25.578	26.46	.49171127	.5464331	1.8300502

4.3 Parametric Analysis

@ TANK 2A 0.8 lb residual

1.25 lb dry down return

@ TANK 2B 0.8 lb residual

@ TANK 2C no residual or dry down

All consider starting with 32 lbs of fresh urine.
Variable output as follows:

Switch Conc, Days to switch
Vol. switch, conc at switch (last day)
Avg. rate initial, ave rate mission, last day rate
Time mode 1, time mode 2, total time

```
TYMSHARE    C9 1/20/77  7:09
-LOAD
15%

-SBA

>LOAD TANK2A

FILE NAME NOT IN FILE DIRECTORY
>RU
>LOAD @TANK2A
>RUN
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
? 0
INPUT SWITCH CONCENTRATION
? .05




 5E-02           0
 18.76836        8.2424713E-02
 .9941704        .87867308       .67147515
 .41348875       .58651125       1




 1E-01           0
 9.38418         .16911192
 .99050782       .93057849       .7998786
 .70674438       .29325562       1




 .15             0
 6.25612         .26006162
 .98756459       .94755421       .85294529
 .80449625       .19550375       1




 .2              0
 4.69209         .35527381
 .98444001       .95474315       .88090454
 .85337219       .14662781       1




 .25             0
 3.753672        .4547485
 .98188535       .95839073       .89794697
 .88269775       .11730225       1
```

.3	0	
3.12806	.55848567	
.97952149	.96017929	.9090893
.90224813	9.7751875E-02	1

.35	0	
2.6811943	.66648534	
.97688962	.96056474	.91640329
.91621268	8.3787321E-02	1

5E-02	5	
18.76836	8.2424713E-02	
.9941704	.87855971	.67147515
.41348875	.58651125	1

1E-01	5	
9.38418	.16911192	
.99050782	.93074053	.7998786
.70674438	.29325562	1

.15	5	
6.25612	.26006162	
.98756459	.94810798	.85294529
.80449625	.19550375	1

.2	5	
4.69209	.35527381	
.98444001	.95575691	.88090454
.85337219	.14662781	1

.25	5	
3.753672	.4547485	
.98188535	.95980544	.89794697
.88269775	.11730225	1

.3	5	
3.12806	.55848567	
.97952149	.96197269	.9090893
.90224813	9.7751875E-02	1

.35	5	
2.6811943	.66648534	
.97688962	.96277658	.91640329
.91621268	8.3787321E-02	1

5E-02	10	
18.76836	8.2424713E-02	
.9941704	.8767382	.67147515
.41348875	.58651125	1

1E-01	10	
9.38418	.16911192	
.99050782	.92762906	.7998786
.70674438	.29325562	1

.15	10	
6.25612	.26006162	
.98756459	.94479469	.85294529
.80449625	.19550375	1

.2	10	
4.69209	.35527381	
.98444001	.95260088	.88090454
.85337219	.14662781	1

.25	10	
3.753672	.4547485	
.98188535	.95686953	.89794697
.88269775	.11730225	1

.3	10	
3.12806	.55848567	
.97952149	.9592984	.9090893
.90224813	9.7751875E-02	1

.35	10	
2.6811943	.66648534	
.97688962	.96044376	.91640329
.91621268	8.3787321E-02	1

5E-02	15	
18.76836	8.2424713E-02	
.9941704	.8717264	.67147515
.41348875	.58651125	1

1E-01	15	
9.38418	.16911192	
.99050782	.91845298	.7998786
.70674438	.29325562	1

.15	15	
6.25612	.26006162	
.98756459	.93432839	.85294529
.80449625	.19550375	1

.2	15	
4.69209	.35527381	
.98444001	.9417284	.88090454
.85337219	.14662781	1

.25	15	
3.753672	.4547485	
.98188535	.9458752	.89794697
.88269775	.11730225	1

```
 .3              15
 3.12806         .55848567
 .97952149       .94833893      .9090893
 .90224813       9.7751875E-02  1



 .35             15
 2.6811943       .66648534
 .97688962       .94966883      .91640329
 .91621268       8.3787321E-02  1

>0

-3BA

>LOAD @TANK2B
>RUN
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
0
INPUT SWITCH CONCENTRATION
.05



 5E-02           0
 18.07936        5.0992956E-02
 .99430118       .88248136      .67959941
 .43502          .56498         1



 1E-01           0
 9.03968         .10641085
 .99078041       .93282342      .80569947
 .71751          .28249         1



 .15             0
 6.0264533       .16625367
 .98795807       .9492605       .85747568
 .81167333       .18832667      1



 .2              0
 4.51984         .23052143
 .98493442       .95620183      .8846614
 .858755         .141245        1
```

.25	0	
3.615872	.29921413	
.98247378	.95973143	.90121308
.887004	.112996	1

.3	0	
3.0132267	.37233176	
.98033857	.961588	.91213617
.90583667	9.4163333E-02	1

.35	0	
2.5827657	.44987433	
.97780432	.96196832	.91923429
.91928857	8.0711429E-02	1

5E-02	5	
18.07936	5.0992956E-02	
.99430118	.88235358	.67959941
.43502	.56498	1

1E-01	5	
9.03968	.10641085	
.99078041	.93295981	.80569947
.71751	.28249	1

.15	5	
6.0264533	.16625367	
.98795807	.949772	.85747568
.81167333	.18832667	1

.2	5	
4.51984	.23052143	
.98493442	.95715824	.8846614
.858755	.141245	1

.25	5	
3.615872	.29921413	
.98247378	.96107374	.90121308
.887004	.112996	1

.3	5	
3.0132267	.37233176	
.98033857	.96327462	.91213617
.90583667	9.4163333E-02	1

.35	5	
2.5827657	.44987433	
.97780432	.96405771	.91923429
.91928857	8.0711429E-02	1

5E-02	10	
18.07936	5.0992956E-02	
.99430118	.88041343	.67959941
.43502	.56498	1

1E-01	10	
9.03968	.10641085	
.99078041	.92975734	.80569947
.71751	.28249	1

.15	10	
6.0264533	.16625367	
.98795807	.94636867	.85747568
.81167333	.18832667	1

.2	10	
4.51984	.23052143	
.98493442	.95390665	.8846614
.858755	.141245	1

.25	10	
3.615872	.29921413	
.98247378	.95803299	.90121308
.887004	.112996	1

.3	10	
3.0132267	.37233176	
.98033857	.96046395	.91213617
.90583667	9.4163333E-02	1

.35	10	
2.5327657	.44987433	
.97780432	.96157518	.91923429
.91928857	8.0711429E-02	1

5E-02	15	
18.07936	5.0992956E-02	
.99430118	.87509073	.67959941
.43502	.56498	1

1E-01	15	
9.03968	.10641085	
.99078041	.92037217	.80569947
.71751	.28249	1

.15	15	
6.0264533	.16625367	
.98795807	.93572726	.85747568
.81167333	.18832667	1

.2	15	
4.51984	.23052143	
.98493442	.94287166	.8846614
.858755	.141245	1

```
 .25                15
 3.615872           .29921413
 .98247378          .94687806         .90121308
 .887004            .112996           1



 .3                 15
 3.0132267          .37233176
 .98033857          .949319           .91213617
 .90583667          9.4163333E-02     1



 .35                15
 2.5827657          .44987433
 .97780432          .95060654         .91923429
 .91928857          8.0711429E-02     1

>Q

-IBA

>LOAD @TANK2C
>RUN
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
0
INPUT SWITCH CONCENTRATION
.05



 5E-02              0
 17.6384            5E-02
 .99430118          .88490861         .68488649
 .4488              .5512             1



 1E-01              0
 8.8192             1E-01
 .99078041          .93415621         .80938718
 .7244              .2756             1



 .15                0
 5.8794667          .15
 .98795807          .95016824         .86024679
 .81626667          .18373333         1
```

.2	0	
4.4096	.2	
.98493442	.95688266	.88686357
.8622	.1378	1

.25	0	
3.52768	.25	
.98247378	.96027358	.90303479
.88976	.11024	1

.3	0	
2.9397333	.3	
.98033857	.96203679	.91368655
.90813333	9.1866667E-02	1

.35	0	
2.5197714	.35	
.97780432	.96234846	.92057923
.92125714	7.8742857E-02	1

5E-02	5	
17.6384	5E-02	
.99430118	.88477606	.68488649
.4488	.5512	1

1E-01	5	
8.8192	1E-01	
.99078041	.93429431	.80938718
.7244	.2756	1

.15	5	
5.8794667	.15	
.98795807	.95068362	.86024679
.81626667	.18373333	1

.2	5	
4.4096	.2	
.98493442	.95784429	.88686357
.8622	.1378	1

.25	5	
3.52768	.25	
.98247378	.9616216	.90303479
.88976	.11024	1

.3	5	
2.9397333	.3	
.98033857	.96372928	.91368655
.90813333	9.1866667E-02	1

.35	5	
2.5197714	.35	
.97730432	.96444399	.92057923
.92125714	7.8742857E-02	1

5E-02	10	
17.6384	5E-02	
.99430118	.8827636	.68488649
.4488	.5512	1

1E-01	10	
8.8192	1E-01	
.99078041	.93105195	.80938718
.7244	.2756	1

.15	10	
5.8794667	.15	
.98795807	.94725454	.86024679
.81626667	.18373333	1

.2	10	
4.4096	.2	
.98493442	.95457503	.88686357
.8622	.1378	1

.25	10	
3.52768	.25	
.98247378	.95856795	.90303479
.88976	.11024	1

.3	10	
2.9397333	.3	
.98033857	.96090885	.91368655
.90813333	9.1866667E-02	1

.35	10	
2.5197714	.35	
.97780432	.96195416	.92057923
.92125714	7.8742857E-02	1

5E-02	15	
17.6384	5E-02	
.99430118	.87724409	.68488649
.4488	.5512	1

1E-01	15	
8.8192	1E-01	
.99078041	.92155131	.80938718
.7244	.2756	1

.15	15	
5.8794667	.15	
.98795807	.93653366	.86024679
.81626667	.18373333	1

```
.2                 15
4.4096             .2
.98493442          .94348084         .88686357
.8622              .1378             1



.25                15
3.52768            .25
.98247378          .94736634         .90303479
.88976             .11024            1



.3                 15
2.9397333          .3
.98033857          .94972568         .91368655
.90813333          9.1866667E-02     1



.35                15
2.5197714          .35
.97780432          .95095369         .92057923
.92125714          7.8742857E-02     1

>Q

-LOAD
13%

-LOG

CPU TIME: 224 SECS.
TERMINAL TIME: 0:8:56

PLEASE LOG IN:
```

4.4 Proof Runs for Last Day Switch Concentration of 20%

(1) TANK 2A	0.8 residual/1.25 dry down
(2) TANK 2B	1.25 drydown
(3) TANK 2C	no residual or dry down

MATA = last day performance before switching - over

initial waste quantity, final waste quantity, salt conc. ave, process rate, time fracti

MAT B same as previous output sheets

```
>LIST
10021  PRINT FOR I = 1 TO 5
10022  MAT PRINT A
10023  PRINT FOR I = 1 TO 5
10024  MAT PRINT A
10025  END
>400    PRINT FOR I = 1 TO 10
>EDIT 10025
10025  END
10026  END
>10025  PRINT FOR I = 1 TO 20
>EDIT 102_024
10024  MAT PRINT A
10024  MAT PRINT B
>SAVE AAA
 OLD FILE
LOAD @TAN>K2A
>RUN
```

```
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
? 0
INPUT SWITCH CONCENTRATION
? .12
```

.12	0	
7.82015	.2049803	
.98929929	.93923515	.82574982
.75562031	.24437969	1

MATA

32.8	30.302015	2.9742885E-02	.99553857	2.5091795
30.302015	27.80403	3.2300185E-02	.99515497	2.5101467
27.80403	25.306045	3.5338606E-02	.99469921	2.5112969
25.306045	22.80806	3.9008021E-02	.9941488	2.5126872
22.80806	20.310075	4.3527764E-02	.99294167	2.5157419
20.310075	17.81209	4.9232146E-02	.99123036	2.5200853
17.81209	15.314105	5.6657156E-02	.98900285	2.5257612
15.314105	12.81612	6.6719552E-02	.98598413	2.5334941
12.81612	10.318135	8.1128007E-02	.981577	2.5448691
10.318135	7.82015	.10347373	.97319735	2.5667815
7.82015	0	0	0	0

MATB

0	.882	8.3340893E-03	.99874989	1.008479	2.9332018E-02
.882	1.764	2.5002268E-02	.99624966	1.0090931	2.9943919E-02
1.764	2.646	4.1670446E-02	.99349887	1.0097723	3.055582E-02
2.646	3.528	5.8338625E-02	.98849841	1.0110166	3.1167721E-02
3.528	4.41	7.5006803E-02	.98349796	1.0122736	3.1779622E-02
4.41	5.292	9.1674982E-02	.97762188	1.0137671	3.2391522E-02
5.292	6.174	.10834316	.97137131	1.0153756	3.3003423E-02
6.174	7.056	.12501134	.96374263	1.017367	3.3615324E-02
7.056	7.938	.14167952	.95290831	1.0202501	3.4227225E-02
7.938	8.82	.1583477	.942074	1.0231995	3.4839126E-02
8.82	9.702	.17501587	.93199048	1.0260061	3.5451027E-02
9.702	10.584	.19168405	.92198957	1.0288503	3.6062927E-02
10.584	11.466	.20835223	.91010941	1.0323103	3.6674828E-02
11.466	12.348	.22502041	.89635816	1.0364297	3.7286729E-02
12.348	13.23	.24168859	.88252249	1.0407039	3.789863E-02
13.23	14.112	.25835677	.86793783	1.045357	3.8510531E-02
14.112	14.994	.27502495	.85335317	1.0501692	3.9122432E-02
14.994	15.876	.29169312	.83496825	1.0564749	3.9734332E-02
15.876	16.758	.3083613	.81496644	1.0636582	4.0346233E-02
16.758	17.64	.32502948	.79471315	1.0713002	4.0958134E-02
17.64	18.522	.34169766	.77387793	1.0795793	4.1570035E-02
18.522	19.404	.35836584	.7530427	1.0883165	4.2181936E-02
19.404	20.286	.37503402	.73183163	1.0977223	4.2793836E-02
20.286	21.168	.3917022	.7105797	1.1077094	4.3405737E-02
21.168	22.05	.40837037	.68639814	1.1198254	4.4017638E-02
22.05	22.932	.42503855	.65931235	1.1344519	4.4629539E-02
22.932	23.814	.44170673	.63197055	1.1504882	4.524144E-02
23.814	24.696	.45837491	.60238454	1.1694806	4.5853341E-02
24.696	25.578	.47504309	.57279852	1.1904351	4.6465241E-02
25.578	26.46	.49171127	.5464331	1.2110205	4.7077142E-02
26.46	0	0	0	0	0

```
>Q

-SBA

>LOAD AAA
>LOAD @TANK2B
>RUN
```

```
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
0
INPUT SWITCH CONCENTRATION
.18
```

.18	0	
5.0220444	.20428334	
.98607532	.95401298	.87552466
.84306111	.15693889	1

MATA

32.8	30.022204	2.8778614E-02	.99568321	2.7898387
30.022204	27.244409	3.1570507E-02	.99526442	2.7910126
27.244409	24.466613	3.4962295E-02	.99475566	2.7924401
24.466613	21.688818	3.9170602E-02	.99412441	2.7942132
21.688818	18.911022	4.4530619E-02	.99264081	2.7983894
18.911022	16.133227	5.1590091E-02	.99052297	2.8043727
16.133227	13.355431	6.1309539E-02	.98760714	2.8126524
13.355431	10.577636	7.5541343E-02	.9833376	2.8248646
10.577636	7.79984	9.8377821E-02	.97510832	2.8487046
7.79984	5.0220444	.14100392	.95334745	2.9137284
5.0220444	0	0	0	0

MATB

0	.882	8.3340893E-03	.99874989	1.0121016	3.1278049E-02
.882	1.764	2.5002268E-02	.99624966	1.0124959	3.1278049E-02
1.764	2.646	4.1670446E-02	.99349887	1.0129321	3.1278049E-02
2.646	3.528	5.8338625E-02	.98849841	1.0137312	3.1278049E-02
3.528	4.41	7.5006803E-02	.98349796	1.0145384	3.1278049E-02
4.41	5.292	9.1674982E-02	.97762188	1.0154975	3.1278049E-02
5.292	6.174	.10834316	.97137131	1.0165305	3.1278049E-02
6.174	7.056	.12501134	.96374263	1.0178094	3.1278049E-02
7.056	7.938	.14167952	.95290831	1.0196609	3.1278049E-02
7.938	8.82	.1583477	.942074	1.0215549	3.1278049E-02
8.82	9.702	.17501587	.93199048	1.0233573	3.1278049E-02
9.702	10.584	.19168405	.92198957	1.0251839	3.1278049E-02
10.584	11.466	.20835223	.91010941	1.0274058	3.1278049E-02
11.466	12.348	.22502041	.89635816	1.0300513	3.1278049E-02
12.348	13.23	.24168859	.88252249	1.0327961	3.1278049E-02
13.23	14.112	.25835677	.86793783	1.0357844	3.1278049E-02
14.112	14.994	.27502495	.85335317	1.0388747	3.1278049E-02
14.994	15.876	.29169312	.83496825	1.0429241	3.1278049E-02
15.876	16.758	.3083613	.81496644	1.0475372	3.1278049E-02
16.758	17.64	.32502948	.79471315	1.0524449	3.1278049E-02
17.64	18.522	.34169766	.77387793	1.0577616	3.1278049E-02
18.522	19.404	.35836584	.7530427	1.0633726	3.1278049E-02
19.404	20.286	.37503402	.73183163	1.069413	3.1278049E-02
20.286	21.168	.3917022	.7105797	1.0758266	3.1278049E-02
21.168	22.05	.40837037	.68639814	1.0836074	3.1278049E-02
22.05	22.932	.42503855	.65931235	1.0930004	3.1278049E-02
22.932	23.814	.44170673	.63197055	1.1032988	3.1278049E-02
23.814	24.696	.45837491	.60238454	1.1154957	3.1278049E-02
24.696	25.578	.47504309	.57279852	1.1289524	3.1278049E-02
25.578	26.46	.49171127	.5464331	1.1421723	3.1278049E-02
26.46	0	0	0	0	0

```
>Q

--SBA

>LOAD AAA
>LOAD @TANK2C
>RUN
```

```
INPUT DAILY MATRIX INCREMENTS
INPUT DAYS IN MODE 1
0
INPUT SWITCH CONCENTRATION
.2
```

.2	0	
4.4096	.2	
.98493442	.95688266	.88686357
.8622	.1378	1

MATA

32	29.24096	2.8801639E-02	.99567975	2.7710115
29.24096	26.48192	3.1653784E-02	.99525193	2.7722026
26.48192	23.72288	3.5132896E-02	.99473007	2.773657
23.72288	20.96384	3.9471234E-02	.99407931	2.7754727
20.96384	18.2048	4.5031944E-02	.99249042	2.779916
18.2048	15.44576	5.2416364E-02	.99027509	2.7861349
15.44576	12.68672	6.2697636E-02	.98719071	2.7948399
12.68672	9.92768	7.7996321E-02	.9826011	2.8078943
9.92768	7.16864	.10317074	.97331097	2.8346953
7.16864	4.4096	.15234094	.94597839	2.9165994
4.4096	0	0	0	0

MATB

0	2.756E-02	.882	8.3340893E-03	.99874989	1.0133607
.882	2.756E-02	1.764	2.5002268E-02	.99624966	1.013707
1.764	2.756E-02	2.646	4.1670446E-02	.99349887	1.01409
2.646	2.756E-02	3.528	5.8338625E-02	.98849841	1.0147916
3.528	2.756E-02	4.41	7.5006803E-02	.98349796	1.0155004
4.41	2.756E-02	5.292	9.1674982E-02	.97762188	1.0163425
5.292	2.756E-02	6.174	.10834316	.97137131	1.0172495
6.174	2.756E-02	7.056	.12501134	.96374263	1.0183725
7.056	2.756E-02	7.938	.14167952	.95290831	1.0199982
7.938	2.756E-02	8.82	.1583477	.942074	1.0216612
8.82	2.756E-02	9.702	.17501587	.93199048	1.0232438
9.702	2.756E-02	10.584	.19168405	.92198957	1.0248476
10.584	2.756E-02	11.466	.20835223	.91010941	1.0267986
11.466	2.756E-02	12.348	.22502041	.89635816	1.0291214
12.348	2.756E-02	13.23	.24168859	.88252249	1.0315316
13.23	2.756E-02	14.112	.25835677	.86793783	1.0341554
14.112	2.756E-02	14.994	.27502495	.85335317	1.0368689
14.994	2.756E-02	15.876	.29169312	.83496825	1.0404244
15.876	2.756E-02	16.758	.3083613	.81496644	1.044475
16.758	2.756E-02	17.64	.32502948	.79471315	1.0487841
17.64	2.756E-02	18.522	.34169766	.77387793	1.0534525
18.522	2.756E-02	19.404	.35836584	.7530427	1.0583792
19.404	2.756E-02	20.286	.37503402	.73183163	1.0636829
20.286	2.756E-02	21.168	.3917022	.7105797	1.0693144
21.168	2.756E-02	22.05	.40837037	.68639814	1.0761464
22.05	2.756E-02	22.932	.42503855	.65931235	1.0843939
22.932	2.756E-02	23.814	.44170673	.63197055	1.0934364
23.814	2.756E-02	24.696	.45837491	.60238454	1.1041458
24.696	2.756E-02	25.578	.47504309	.57279852	1.1159615
25.578	2.756E-02	26.46	.49171127	.5464331	1.1275692
26.46	0	0	0	0	0

Appendix D

Subsystem Performance Investigations

COMPUTER PROGRAMS

Due to the large number of VCD process variables, assessment of machine performance requires computerized performance programs. These include a performance prediction program, a steady state performance model, and a transient performance model. The sections which follow present a brief review of machine operation, describe the capabilities of each program, and present instructions for use of the programs including entry of data and data interpretation.

Machine Operation

The VCD machine consists of a boiler, a condensor, a compressor, a combined feed - recycle-condensate pump, waste feed tank, a recycle tank, and various other mechanical components.

In normal operation fluid from the waste feed tank or recycle tank is constantly recirculated through the boiler by the recycle and feed sections of the pump. The vapor in the boiler is pulled off by the compressor and condenses and is removed by the condensate section of the pump. The recycle/condensate ratio is about 4 or 5 to 1.

The machine is usually operated in the low solids mode. This means that during the first part of the day fluid from the boiler is recirculated through the feed tank, and during the second part of the day it is recirculated through the recycle tank. The point at which the change occurs is called the switch point. At the end of the day the unit enters drydown. At this time the fluid in the boiler is removed and returned through the recycle tank to the waste tank.

Performance Prediction Program

The program allows determination of the approximate daily operating time and production rate for any feed cycle, and any number of continuous days of operation. The program utilizes select transient program data as input and will therefore account for reduced process rates during startup and with increases in feed solids.

As the program was designed to utilize a minimum of computer time, certain simplifying approximations were necessary. Due to the method of approximation the program predicts results which are slightly more optimistic than will be experienced in actual machine operation. This is due to the effect of neglecting thermal inertia after the "switch" to low solids has occurred.

The sections which follow provide a more detailed description of the contents of the program, and describe in detail how to use this program.

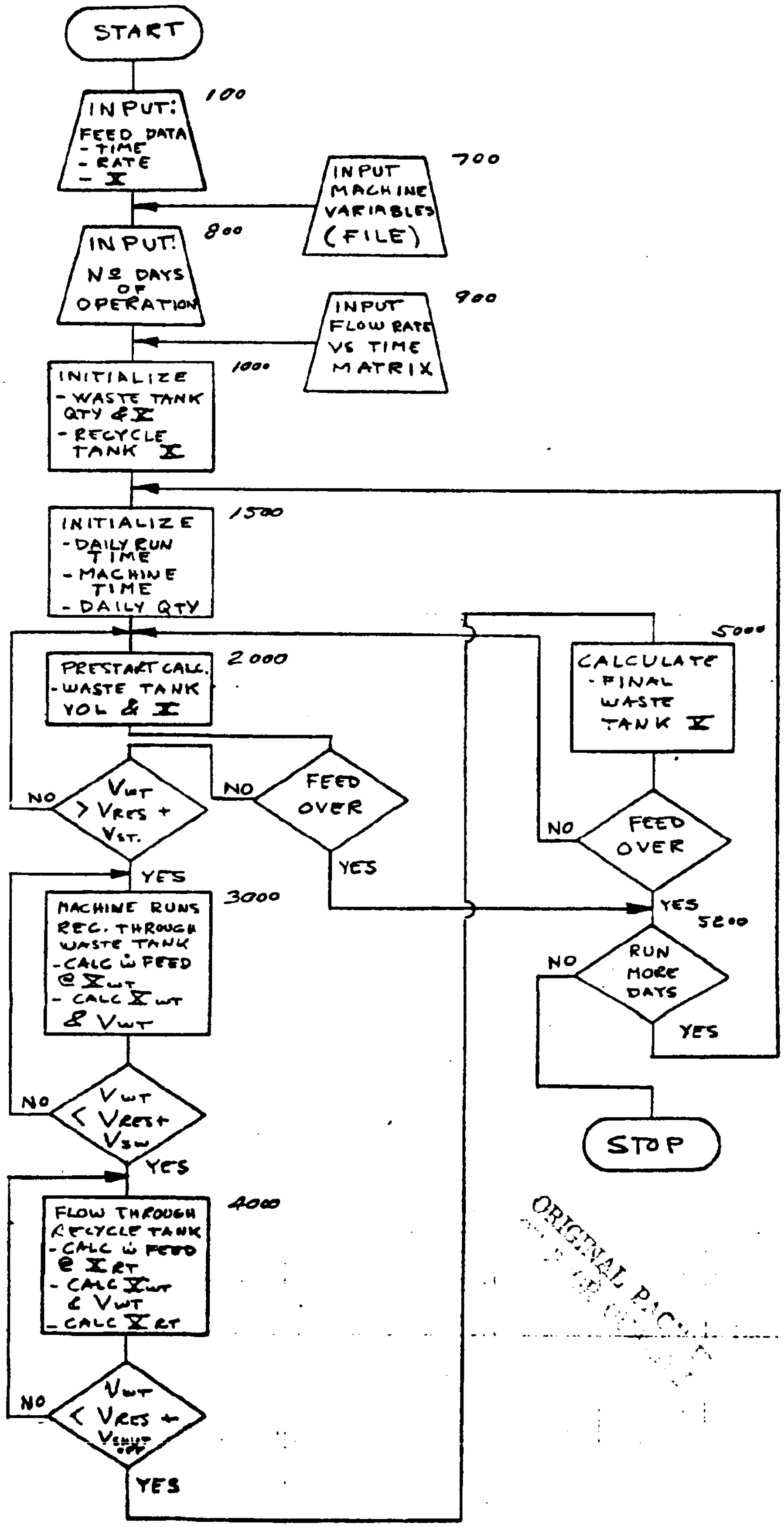
Program Description

The complete program consists of the main program and two data files. The first, the flow rate versus time and percent solids matrix, is derived from transient program runs and must be entered into a file. The second, the feed schedule, can be entered from a data file or from the terminal. If entered at the terminal, the data can also be easily stored on a file.

Figure 1 presents a flow chart of the program. The numbers refer to steps in the program. It begins in steps 100-800 with the input of feed data, machine variables (these are stored in the program), and the number of days of continuous operation desired.

Figure 1

VCD PERFORMANCE PREDICTION PROGRAM



The program then, in steps 900-1000, reads the input flow rate versus time matrix and initializes in steps 1000 -1800, the waste tank quantity and solute weight fraction (X), and the recycle tank X. After initialization of the daily run time, machine time, and daily quantity, the first days calculation is begun.

In step 2000, the program incrementally adds feed to the waste tank, as dictated by the feed schedule, and checks to see if the volume of fluid in the waste tank exceeds the start point volume. It also computes the X of the waste tank. When the volume is large enough the VCD machine then starts and the program transfers to step 3000. If the daily feed cycle is completed before the machine starts, the program transfers to step 5200 to see if another day of operation is desired. Printout of data occurs at the end of each major program section.

After starting, in steps 3000 - 4000, recycle is through the waste tank. The program incrementally adds a small volume of fluid from the feed schedule, and calculates (from the flow rate vs time matrix at the waste tank X) the incremental amount of fluid processed. Calculated variables are the waste tank volume and X.

The process rate calculated by the program is based on a data file which contains data from transient program runs. Double interpolation is provided (in subroutine 11000) for both time and percent solids. At the beginning of each day the daily time and machine time is initialized. When the machine starts, the machine time count incrementally advances, and this, in conjunction with the data table reduces the machine process rate for the first hours of operation thus simulating warmup. After the machine time reaches the largest table value the only interpolation is for percent solids. Therefore, no more transients occur during the daily operation. As there are really slight transients as the feed X is changed, especially at switches, the calculated daily process quantity is slightly optimistic.

When the waste tank volume goes below the switch volume,the program transfers to step 4000 and recycle through the waste tank is begun.

Again, the program incrementally adds a small volume of fluid and calculates the volume processed. This time however, the volume processed is based on the recycle tank X. Calculated variables are the waste tank X and volume, and the recycle tank X. When the waste tank volume reaches the shutoff point the program transfers to step 5000 and calculates the final waste tank X.

If the feed is not over the program transfers to 2000 and continues operation for the same day. If enough fluid is fed,the machine will restart.

If the feed is over and another day of operation is desired, the program transfers to 1500 and initializes the daily times and process quantity. Operation is then the same as previously described. When the proper number of days have been run, the program prints the final data and stops.

Program Operation

Before running the program, the flow rate versus time and percent solids matrix must be loaded into a file. It must be an 8x8 matrix unless internal program dimensions are changed. It is of the form Mat (X,X). The first row (1,2) to (1,8) contains the percent solids. (1,1) contains a 0.

The first column (2,1) to (2,8) contains the hours of operation. The other matrix points contain the values of the ratio of actual machine process flow to the clean machine process flow at steady state. These are obtained by running the transient program for each percent solids and inputting the ratios corresponding to the proper times. A typical data file is shown in Table 1. .

Table 1

TS Data

0	.00	5.00	10.00	15.00	20.00	30.00	50.00
0	.60	.58	.56	.52	.48	.38	.30
1	.70	.68	.66	.61	.56	.44	.35
2	.80	.78	.75	.70	.64	.50	.40
3	.90	.87	.85	.78	.72	.57	.45
4	.95	.92	.89	.83	.76	.60	.48
5	.97	.94	.91	.84	.78	.61	.49
6	1.00	.97	.94	.87	.80	.63	.50

The actual program is self documenting. Feed data can be input from a file or entered at the terminal. Feed data consists of entering the number of feed changes during the daily cycle, the time at which the feed rate ends and a new feed rate begins, the feed rate in cubic feet per hour, and the feed solute weight fraction (X). A typical feed file is shown in Table 2.

Output on a daily basis is the startup time and startup waste tank X, the switch time and the corresponding waste and recycle tank X, the shutoff time and shutoff X for both waste and recycle tanks, the final waste tank X, and the quantity of water processed during the day in cubic feet of clean water. The day and waste tank quantity is also provided.

It should be noted that the VCD machine will start anytime the waste tank quantity exceeds the start point. Also, the VCD machine will switch to recycle through the recycle tank only once in an operating cycle, and will shutdown when the waste tank quantity reaches the shutoff point.

If there is still feed left in the feed cycle, the waste tank will continue to fill and the next day's operation will begin with the tank partially full. If there is enough feed, the machine will even restart again the same day.

The time indicated on the printout is the time from initiation of the feed cycle. If the last daily shutoff time is greater than 24 hrs. this means that the machine variables and/or feed schedule are not compatible with daily operation, and even though the machine prints out sequential days, the feed cannot begin at the same time each day. If the shutoff time is less than 24 hours then the times listed are daily times from feed initiation.

Table 2
D SOLIDS 4

COPY DSOLIDS4 TO T

17

1	1	1.22E-02	2E-02
2	2	0	0
3	3	1.22E-02	2E-02
4	4	0	0
5	5	1.22E-02	2E-02
6	7	3.66E-02	2E-02
7	8	4.88E-02	2E-02
8	9	3.66E-02	2E-02
9	10	2.44E-02	2E-02
10	13	3.66E-02	2E-02
11	16	2.44E-02	2E-02
12	17	1.22E-02	2E-02
13	18	2.44E-02	2E-02
14	19	3.66E-02	2E-02
15	20	2.44E-02	2E-02
16	21	1.22E-02	2E-02
17	24	0	0

Machine variables such as volumes and the basic clean process rate are in the program in steps 700-800. Also included is the basic time increment used in the program for the finite elements. Any of these can easily be changed before the program is run.

The program listing (SOLIDS 4), variable list, variable cross reference, and a sample printout are presented.

```
SYSTEM: C9
FILE: SOLIDS4                                          APRIL 6, 1978  9:17 AM PST
CHECKSUM: 66100466

1!PROGRAM - SOLIDS4
100 !SOLIDS MODE WITH SWITCHED RECYCLE
200 !QUESTIONS
210 PRINT"IS INPUT OF FEED DATA FROM FILE DESIRED(Y OR N)":
220 INPUT N2
230 IF N2="Y" THEN 240 ELSE 310
240 PRINT"WHAT FILE CONTAINS FEED DATA":
250 INPUT N3
260 OPEN N3,INPUT,1
270 INPUT FROM 1:A1
280 MAT INPUT FROM 1:B(A1,4)
290 CLOSE 1
300 GO TO 520
310 PRINT"INPUT NUMBER OF DAILY RATE CHANGES":
320 INPUT A1
330 MAT B=ZER(A1,4)
360 PRINT"INPUT TIME OF CHANGE(HRS),FEED RATE(CU FT/HR),FEED %(LB SOLIDS/
LB LIQUID)                SEPARATED BY COMMAS"
410 FOR J= 1 TO A1
420 B(J,1)=J
470 PRINT J:
480 FOR K=2 TO 4
490 INPUT B(J,K)
500 NEXT K
510 NEXT J
520 PRINT"IS MATRIX PRINTOUT DESIRED(Y OR N)":
530 INPUT N4
540 IF N4="Y" THEN 550 ELSE 560
550 MAT PRINT B
560 PRINT"ARE ANY CHANGES DESIRED IN MAT B(Y OR N)":
570 INPUT N5
580 IF N5="Y" THEN 590 ELSE 610
590 PRINT"AFTER CHANGES GO TO  610"
600 PAUSE
610 PRINT"IS DATA MATRIX TO BE SAVED ON FILE(Y OR N)":
620 INPUT N6
630 IF N6="Y" THEN 640 ELSE 700
640 PRINT"WHAT IS NAME OF FILE":
650 INPUT F1
660 OPEN F1,OUTPUT,2
670 WRITE ON 2:A1
680 MAT WRITE ON 2:B
690 CLOSE 2
700!CONSTANT TERMS
710 V1=.039           !RESIDUAL WASTE TANK VOLUME(CU FT)
720 V2=.162           !START POINT VOLUME ABOVE RESIDUAL(CU FT)
730 V3=.128           !SWITCH POINT VOLUME ABOVE RESIDUAL(CU FT)
740 V5=.012           !BOILER VOLUME(CU FT)
750 V6=.685           !RECYCLE TANK VOLUME(CU FT)
760 V7=.0128          !SHUTOFF POINT VOLUME ABOVE RESIDUAL(CU FT)
770 W1=.056                  !BASIC MACHINE CLEAN PROCESS RATE(CU FT/HR)
780 T1=.5                    !BASIC TIME INCREMENT(HRS)
800 PRINT"WHAT IS NUMBER OF DAYS OF CONTINUOUS OPERATION":
810 INPUT N1
900 !INPUT OF FLOW RATE VS TIME DATA MATRIX
```

```
910 OPEN "TSDATA",INPUT,1
920 MAT INPUT FROM 1:E(8,8)
930 CLOSE 1
1000! INITIALIZATION OF VOLUMES
1100 X3=0
1200 X4=0
1300 V4=V1+V7+V5
1400 FOR K=1 TO N1
1500!INITIALIZATION OF TIMES
1510 T=0
1520 C=.5*T1                    !INITIALIZE MACHINE START TIME
1530 Q1=0                       !INITIALIZE CUMULATIVE VOLUME
1920 PRINT"DAY ":K
2000!PRESTARTUP-WASTE TANK FILLING
2100!FEED RATE EVALUATION
2110 FOR J=1 TO A1
2120 IF B(J,2)> T THEN 2170
2130 NEXT J
2140 V8=0
2150 X9=0
2160 GO TO 5200
2170 V8=B(J,3)
2180 X9=B(J,4)
2300!WASTE TANK X
2310 X3=(V4*(X3+2.08)*X3+V8*T1*(X9+2.08)*X9)/(V4*(X3+2.08)+V8*T1*(X9+2.08)
&:)
2400 V4=V4+V8*T1                !WASTE TANK VOL(CU FT)
2500 T=T+T1
2600 IF V4>=(V2+V1) THEN 2800 ELSE 2000
2800!DATA PRINTOUT FOR STARTUP
2810 PRINT"STARTUP TIME=":T:"  STARTUP WASTE TANK X =":X3
3000!MACHINE STARTED-RECYCLE THROUGH WASTE TANK
3010 V4=V4-V5
3100!FEED RATE EVALUATION
3110 FOR J=1 TO A1
3120 IF B(J,2)> T THEN 3170
3130 NEXT J
3140 V8=0
3150 X9=0
3170 V8=B(J,3)
3180 X9=B(J,4)
3300 !PROCESS RATE CALCULATION
3320 IF C>6 THEN C=6
3325 T2=X3*100
3330 GO SUB 11000
3340 V9=A9*T1                   !VOLUME PROCESSED(LB/INCREMENT)
3350!WASTE TANK X AND VOLUME
3360 X3=((V4+V5)*(X3+2.08)*X3+V8*T1*(X9+2.08)*X9)/((V4+V5)*(X3+2.08)
  +V8*T1*(X9+2.08)-V9*2.08)
3370 V4=V4+V8*T1-V9             !WASTE TANK VOL(CU FT)
3380 T=T +T1
3382 C=C+T1                     !PROCESS TIME AFTER MACHINE STARTS(HRS)
3385 Q1=Q1+V9                   !CUM VOL PROCESSED(CU FT)
3390 IF V4<=(V1+V3) THEN 3800 ELSE 3100
3800!DATA PRINTOUT JUST PRIOR TO SWITCH
3810 PRINT"SWITCH TIME=":T:"  BEFORE SWITCH WASTE TANK X =":X3
3820 PRINT"BEFORE SWITCH RECYCLE TANK X =":X4
4000!AFTER SWITCH-RECYCLE THROUGH WASTE TANK
```

```
4010!ADD 1 BOILER VOLUME OF FLUID AT WASTE TANK X TO RECYCLE TANK LOOP
4020!NEW RECYCLE TANK+BOILER X
4030 X4=(V6*(X4+2.08)*X4+V5*(X3+2.08)*X3)/(V6*(X4+2.08)+V5*(X3+2.08))
4090 PRINT"POST SWITCH RECYCLE TANK X =":X4
4100!FEED RATE EVALUATION
4110 FOR J=1 TO A1
4120 IF B(J,2)> T THEN 4170
4130 NEXT J
4140 V8=0
4150 X9=0
4170 V8=B(J,3)
4180 X9=B(J,4)
4300!PROCESS RATE CALCULATION
4320 IF C>6 THEN C=6
4325 T2=X4*100
4330 GO SUB 11000
4340 V9=A9*T1                       !VOLUME PROCESSED(LB/INCREMENT)
4350!WASTE TANK X AND VOLUME
4360 X3=(V4*(X3+2.08)*X3+V8*T1*(X9+2.08)*X9-V9*(X3+2.08)*X3)/(V4*(X3+2.0
  +V8*T1*(X9+2.08)-V9*(X3+2.08))
4370 V4=V4+V8*T1-V9                 !WASTE TANK VOLUME(CU FT)
4400!RECYCLE TANK X (VOLUME =CONSTANT)
4410 X4=((V5+V6)*(X4+2.08)*X4+V9*(X3+2.08)*X3)/((V5+V6)*(X4+2.08)+V9*(X3-
&:.08)
  -V9*2.08)
4500 T=T+T1
4505 C=C+T1                         !PROCESS TIME AFTER MACHINE STARTS(HRS)
4510 Q1=Q1+V9                       !CUM VOL PROCESSED(CU FT)
4600 IF V4<=(V7+V1)THEN 4800 ELSE 4100
4800!DATA PRINTOUT FOR SHUTOFF
4810 PRINT"SHUTOFF TIME =":T:"  SHUTOFF WASTE TANK X =":X3
4820 PRINT "SHUTOFF RECYCLE TANK X =":X4
5000!PUT BOILER FLUID INTO WASTE TANK-EVALUATE X WASTE TANK
5100 X3=(V5*(X4+2.08)*X4+(V1+V7)*(X3+2.08)*X3)/(V5*(X4+2.08)+(V1+V7)
  *(X3+2.08))
5110 PRINT"FINAL WASTE TANK X =":X3
5120 !CHECK TO SEE IF FEED SCHEDULE IS EXHAUSTED
5130 IF J< A1 THEN 2000
5200!CHECK TO SEE IF ANOTHER DAY OF OPERATION IS DESIRED
5205 PRINT"TOTAL QTY PROCESSED DURING DAY(CU FT)=":Q1
5207 PRINT"DAY END WASTE TANK QUANTITY(CU FT)=":V4
5210 IF K=N1 THEN 6000 ELSE 5220
5220 NEXT K
6000 STOP
11000 ! DOUBLE INTERPOLATION SUBROUTINE FOR FLOW RATE
11040 !PICK FLOW RATE FROM MAT E FOR GIVEN TIME AND % SOLIDS
11050 !INTERPOLATION FOR TIME (HRS)
11060 IF C<E(2,1) THEN 11380
11070 IF C>E(8,1)THEN 11380
11080 FOR I=2 TO 8
11090 IF E(I,1)>=C THEN 11110
11100 NEXT I
11110 IF I=2 THEN 11130
11120 M2=(C-E(I-1,1))/(E(I,1)-E(I-1,1))
11130 !INTERPOLATION FOR % SOLIDS
11140 IF T2<E(1,2) THEN 11400
11150 IF T2>E(1,8) THEN 11400
11160 FOR L=2 TO 8
```

```
11170 IF E(1,L)>= T2 THEN 11190
11180 NEXT L
11190 IF L=2 THEN 11210
11200 M1=(T2-E(1,L-1))/(E(1,L)-E(1,L-1))
11210 IF I=2 THEN 11220 ELSE 11250
11220 C3=E(I,L-1)
11230 C2=E(I,L)
11240 GO TO 11290
11250 IF L=2 THEN 11260 ELSE 11340
11260 C3=0
11270 M1=1
11280 GO TO 11350
11290 IF L=2 THEN 11300 ELSE 11360   !L=2 AND I=2
11300 C3=0
11310 M1=1
11320 C2=E(I,L)
11330 GO TO 11360
11340 C3=E(I-1,L-1)+(E(I,L-1)-E(I-1,L-1))*M2
11350 C2=E(I-1,L)+(E(I,L)-E(I-1,L))*M2
11360 A9=(C3+(C2-C3)*M1)*W1   !FLOW RATE (CU FT/HR)
11370 GO TO 11420
11380 PRINT"INPUT EXCEEDS TIME DATA BASE"
11390 GO TO 11410
11400 PRINT"INPUT EXCEEDS % SOLIDS DATA BASE"
11410 END
11420!CONTINUE

12010 RETURN
```

SOLIDS 4 VARIABLE LIST

A1 = number of daily rate changes

A9 = process flow rate (cu.ft./hr)

C = machine time after start - (hrs)

C2 = constant in rate subroutine

C3 = constant in rate subroutine

F1 = constant in data input routine

I = loop variables

J = loop variables

K = loop variables

L = loop variables

M1 = constants in rate subroutine

M2 = constants in rate subroutine

N1 = number of days of continuous operation

N2 = constants in data input routine

N3 = " " " "

N4 = " " " "

N5 = " " " "

N6 = " " " "

Q1 = cumulative daily water processed (cu.ft.)

T = operating time after feed starts (hrs)

T1 = basic time increment (hrs.)

T2 = percent solids in rate subroutine (percent)

V1 = residual volume in waste tank (cu.ft.)

V2 = startup point volume above residual (cu.ft.)

V3 = switch point volume above residual (cu.ft.)

V4 = waste tank fluid volume (cu.ft.)

V5 = boiler volume (cu.ft.)

V6 = recycle tank volume (cu.ft.)

V7 = shutoff point volume above residual (cu.ft.)

V8 = instantaneous feed rate (cu.ft./hr.)

V9 = incremental flow out (cu.ft./increment)

W1 = basic machine clean flow rate (cu.ft/hr.)

X3 = waste tank solute wgt. fraction (lb solids/ lb liquids)

X4 = recycle tank solute wgt. fraction (lb solids/ lb liquids)

X9 = feed solute wgt fraction (lb solids/ lb liquids)

3/23/78 8:53

```
****************************************************

PROGRAM NAME IS: SOLIDS4



DICTIONARY OF VARIABLES WITH LINE REFERENCES

VAR.--REFERENCE LINE #
NAME
A1   270 280 320 330 410 670 2110 3110 4110 5130
A9   3340 4340 11360 12000
C    1520 3320 3382 4320 4505 11060 11070 11090 11120
C2   11230 11320 11350 11360
C3   11220 11260 11300 11340 11360
F1   650 660
I    11080 11090 11100 11110 11120 11210 11220 11230
     11320 11340 11350
J    410 420 470 490 510 2110 2120 2130 2170 2180 3110
     3120 3130 3170 3180 4110 4120 4130 4170 4180 5130
K    480 490 500 1400 1920 5210 5220
L    11160 11170 11180 11190 11200 11220 11230 11250
     11290 11320 11340 11350
M1   11200 11270 11310 11360
M2   11120 11340 11350
N1   810 1400 5210
N2   220 230
N3   250 260
N4   530 540
N5   570 580
N6   620 630
O1   1530 3385 4510 5205
T    1510 2120 2500 2810 3120 3380 3810 4120 4500 4810
T1   780 1520 2310 2400 2500 3340 3360 3370 3380 3382
     4340 4360 4370 4500 4505
T2   3325 4325 11140 11150 11170 11200
V1   710 1300 2600 3390 4600 5100
V2   720 2600
V3   730 3390
V4   1300 2310 2400 2600 3010 3360 3370 3390 4360 4370
     4600 5207
V5   740 1300 3010 3360 4030 4410 5100
V6   750 4030 4410
V7   760 1300 4600 5100
V8   2140 2170 2310 2400 3140 3170 3360 3370 4140 4170
     4360 4370
V9   3340 3360 3370 3385 4340 4360 4370 4410 4510
W1   770 11360
X3   1100 2310 2810 3325 3360 3810 4030 4360 4410 4810
     5100 5110
```

```
X4   1200 3820 4030 4090 4325 4410 4820 5100
X9   2150 2180 2310 3150 3180 3360 4150 4180 4360


DICTIONARY OF ARRAYS WITH LINE REFERENCES

ARRAY--REFERENCE LINE #
B    280 330 420 490 550 680 2120 2170 2180 3120 3170
     3180 4120 4170 4180
E    920 11060 11070 11090 11120 11140 11150 11170 11200
     11220 11230 11320 11340 11350


CROSS REFERENCE OF LINE NUMBERS

LINE #   REFERENCE LINE #
240      230
310      230
520      300
550      540
560      540
590      580
610      580
640      630
700      630
2000     2600 5130
2170     2120
2800     2600
3100     3390
3170     3120
3800     3390
4100     4600
4170     4120
4800     4600
5200     2160
5220     5210
6000     5210
11000    S3330 S4330
11110    11090
11130    11110
11190    11170
11210    11190
11220    11210
11250    11210
11260    11250
11290    11240
11300    11290
11340    11250
11350    11280
11360    11290 11330
11380    11060 11070
11400    11140 11150
11410    11390
```

11420 11370

◆◆

SOLIDS4 SAMPLE RUN

```
>

RUN
IS INPUT OF FEED DATA FROM FILE DESIRED(Y OR N)? Y
WHAT FILE CONTAINS FEED DATA? DSOLIDS4
IS MATRIX PRINTOUT DESIRED(Y OR N)? N
ARE ANY CHANGES DESIRED IN MAT B(Y OR N)? N
IS DATA MATRIX TO BE SAVED ON FILE(Y OR N)? N
WHAT IS NUMBER OF DAYS OF CONTINUOUS OPERATION? 3
DAY  1
STARTUP TIME= 8  STARTUP WASTE TANK X = 1.4301543E-02
SWITCH TIME= 12.5  BEFORE SWITCH WASTE TANK X = 3.5652081E-02
BEFORE SWITCH RECYCLE TANK X = 0
POST SWITCH RECYCLE TANK X = 6.241459E-04
SHUTOFF TIME = 16.5  SHUTOFF WASTE TANK X = 2.4825793E-02
SHUTOFF RECYCLE TANK X = 1.0004874E-02
FINAL WASTE TANK X = 2.2054117E-02
TOTAL QTY PROCESSED DURING DAY(CU FT)= .42320034
DAY END WASTE TANK QUANTITY(CU FT)= .14099966
DAY  2
STARTUP TIME= 6  STARTUP WASTE TANK X = 2.0357983E-02
SWITCH TIME= 10.5  BEFORE SWITCH WASTE TANK X = 4.2553686E-02
BEFORE SWITCH RECYCLE TANK X = 1.0004874E-02
POST SWITCH RECYCLE TANK X = 1.057383E-02
SHUTOFF TIME = 15.5  SHUTOFF WASTE TANK X = 2.4033479E-02
SHUTOFF RECYCLE TANK X = 2.287731E-02
FINAL WASTE TANK X = 2.3816115E-02
TOTAL QTY PROCESSED DURING DAY(CU FT)= .47632291
DAY END WASTE TANK QUANTITY(CU FT)= .16507675
DAY  3
STARTUP TIME= 5  STARTUP WASTE TANK X = 2.0816261E-02
SWITCH TIME= 9.5  BEFORE SWITCH WASTE TANK X = 4.3862873E-02
BEFORE SWITCH RECYCLE TANK X = 2.287731E-02
POST SWITCH RECYCLE TANK X = 2.3242153E-02
SHUTOFF TIME = 14.5  SHUTOFF WASTE TANK X = 2.3657814E-02
SHUTOFF RECYCLE TANK X = 3.5389136E-02
FINAL WASTE TANK X = 2.5874313E-02
TOTAL QTY PROCESSED DURING DAY(CU FT)= .47408244
DAY END WASTE TANK QUANTITY(CU FT)= .19139431

>
```

Steady State Performance Model

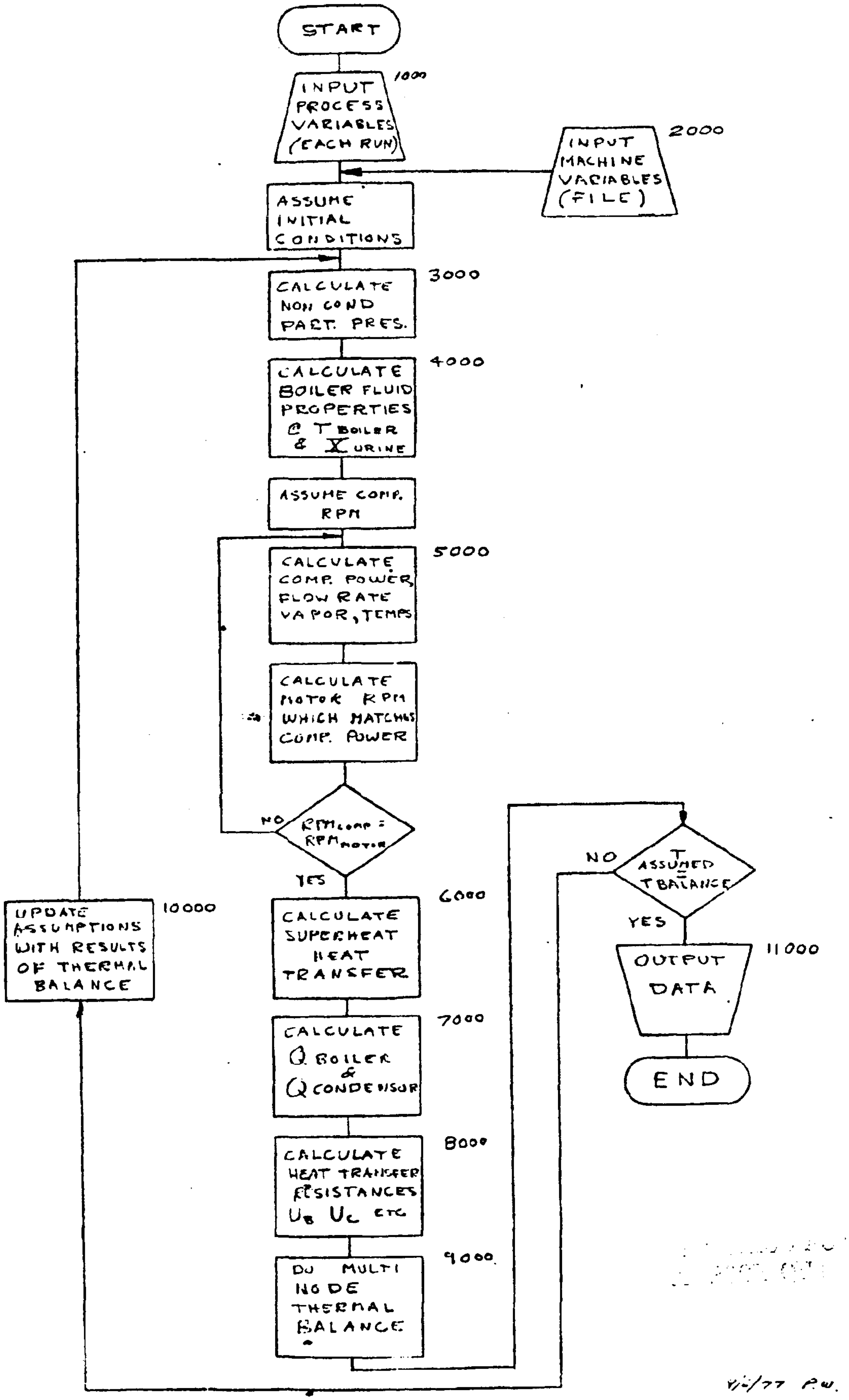
The steady state performance model evaluates the thermodynamic and thermal properties of the VCD unit. It utilizes input data on the machine components such as the motor, compressor, and still to calculate the condensate production rate and motor input power. In addition, it uses heat transfer resistances to determine the temperatures of all machine components in a given operating environment. Provisions for recycle either through the waste tank or recycle tank are provided.

Program Description

The model evaluates the thermodynamic performance of the VCD machine, and simultaneously executes a nodal heat transfer analysis. It utilizes an incremental approach where an initial temperature is assumed, urine and machine properties are calculated at that temperature, and a thermodynamic balance is made. At this point a heat transfer analysis is conducted,and the results of the thermodynamic analysis and heat transfer analysis are compared. If they balance the program ends. If not, the temperatures are updated and the program is rerun until balance occurs.

Figure 2 presents a flow chart of the program. The numbers refer to steps in the program. It begins in steps 1000-2500 with the input of data. Process variables such as the ambient temperature and solute weight fraction are input for each run. Machine variables such as compressor performance constants and boiler size, and all the model resistances are stored in the program so that they don't have to be entered for each run.

Steps 2500-3000 consist of the initialization of temperatures. Since the program iterates there must be some initial temperature differences. For this reason the condensor temperature is set equal to the ambient temperature, and the boiler temperature is set .001 degree below ambient. The compressor RPM and volumetric efficiency for the first iteration are also provided.


START
1000
INPUT PROCESS VARIABLES (EACH RUN)
2000
INPUT MACHINE VARIABLES (FILE)
ASSUME INITIAL CONDITIONS
3000
CALCULATE NON COND PART. PRES.
4000
CALCULATE BOILER FLUID PROPERTIES @ T BOILER & X URINE
ASSUME COMP. RPM
5000
CALCULATE COMP. POWER, FLOW RATE VAPOR, TEMPS
CALCULATE MOTOR RPM WHICH MATCHES COMP. POWER
NO
RPM COMP = RPM MOTOR
YES
6000
CALCULATE SUPERHEAT HEAT TRANSFER
7000
CALCULATE Q BOILER & Q CONDENSOR
8000
CALCULATE HEAT TRANSFER RESISTANCES U B U C ETC
9000
DO MULTI NODE THERMAL BALANCE
10000
UPDATE ASSUMPTIONS WITH RESULTS OF THERMAL BALANCE
NO
T ASSUMED = T BALANCE
YES
11000
OUTPUT DATA
END
4/-/77 P.W.

In steps 3000-4000 the condensor and boiler non condensible partial pressures are calculated. Gas leakage is fixed in the program, and separate boiler and condenser side leaks are provided.

Steps 4000-5000 consist of the calculation of urine properties for the given solute weight fraction and temperature. The data from Reference 1 is stored in the form of power series, exponential, and polynominal curve fits. Properties calculated include vapor pressure and density, liquid density, liquid viscosity, liquid surface tension, liquid specific heat, and liquid thermal conductivity.

Motor input power and condensate flow rate is calculated by balancing motor torque speed characteristics to compressor characteristics. In steps 5000-6000, the program first assumes an initial RPM for the compressor.

It then, using compressor performance characteristics such as the polytropic work of compression and compressor volumetric and mechanical efficiencies, calculates the input torque to the compressor. This torque is then checked against the motor torque speed curve to produce a motor RPM. The initial assumed RPM is then checked against the calculated RPM and the process repeats until the two are essentially equal. A Newton's method convergence routine is used to allow convergence in a minimum number of iterations.

Due to the compression process, the outlet temperature of the vapor is much hotter than the inlet temperature or condenser temperature. The VCD still incorporates a desuperheater where this vapor is passed over the outside shell of the machine before it enters the condenser, thereby losing the excess superheat. In stpps 6000-6300, this calculation is performed.

There is also heat loss from the fluid recycled from the boiler through the waste tank or recycle tank and back again, and from the cold makeup fluid. Steps 6300-7000 consist of this calculation is performed.

There is also heat loss from the fluid recycled from the boiler through the waste tank or recycle tank and back again, and from the cold makeup fluid. Steps 6300-7000 consists of this calculation, and both waste tank and recycle tank options are provided.

Steps 7000 - 8000 the boiler and condenser heat loads are calculated. The boiler heat load is the actual compressor volumetric flow times the vapor density times the heat of vaporization under boiler conditions. The recycle heat loss is subtracted from the boiler mode also. The condenser heat load is the mass of water vapor to the condenser minus the purge pump water, times the heat of condensation at condenser conditions. Left over superheat is added to the condenser node.

The boiler to condenser pressure differential is directly dependent on the boiler to condenser temperature differential. This differential is the driving force necessary to create sufficient heat transfer from the condensing vapor to the boiler fluid. In steps 8000-9000 both the boiler and condenser film coefficients are calculated. The boiling coefficient is based on a pool boiling equation which includes effects of gravity, surface tension, viscosity, density, and thermal conductivity. The condensing coefficient is based on a water film thickness.

Steps 9000-10000 consists of loading the data for, and performing, a system thermal balance. A nodal technique is used, with each important system item being assigned a node number. Thermal resistances which include the effects of radiation, conduction, and convection are then connected between the nodes. In this program the nodal temperatures are solved directly by matrix inversion.

The heat fluxes at each node are summed and temperature differences and resistances are substituted for the heat fluxes. The equations are then arranged so that the constant terms for each temperature are grouped together on one side of the equation, and all constant terms are on the other side. The coefficients of each temperature are then placed into an A matrix, and the constant terms are placed into a C matrix. When the A matrix is inverted and matrix multiplied by the C matrix, a B matrix results which is the temperature of each node. The program uses a library Gauss-Jordon routine to perform this inversion.

After the solution to the nodal balance is complete, the answers are compared with the assumed boiler and condenser temperatures. If they are equal within the specified tolerance, the program transfers to 11000 where the answers are printed and the program ends. If they are not equal, the program transfers to 10000 where the temperature are updated and then to 3000, and the program is rerun.

Program Operation and Data Interpretation

The program is self documenting. Input data consists of the ambient temperature, the solute weight fraction, and the option of recycle through the waste tank or through the recycle tank.

Machine variables are stored in steps 2000-2200. Thermal resistances are stored in steps 2200-2500. Any of these items can be changed as required.

Output data consists of the condensate flow rate out, water flow rate from the purge pump, electrical power into the motor, total condenser pressure, condenser non-condensible partial pressure, total boiler pressure, boiler non-condensible partial pressure, condenser temperature, recycle fluid return temperature, and boiler temperature. Also, Matrix B contains the nodel temperatures and can be printed out if desired. The nodal designations are presented in Figure 3.

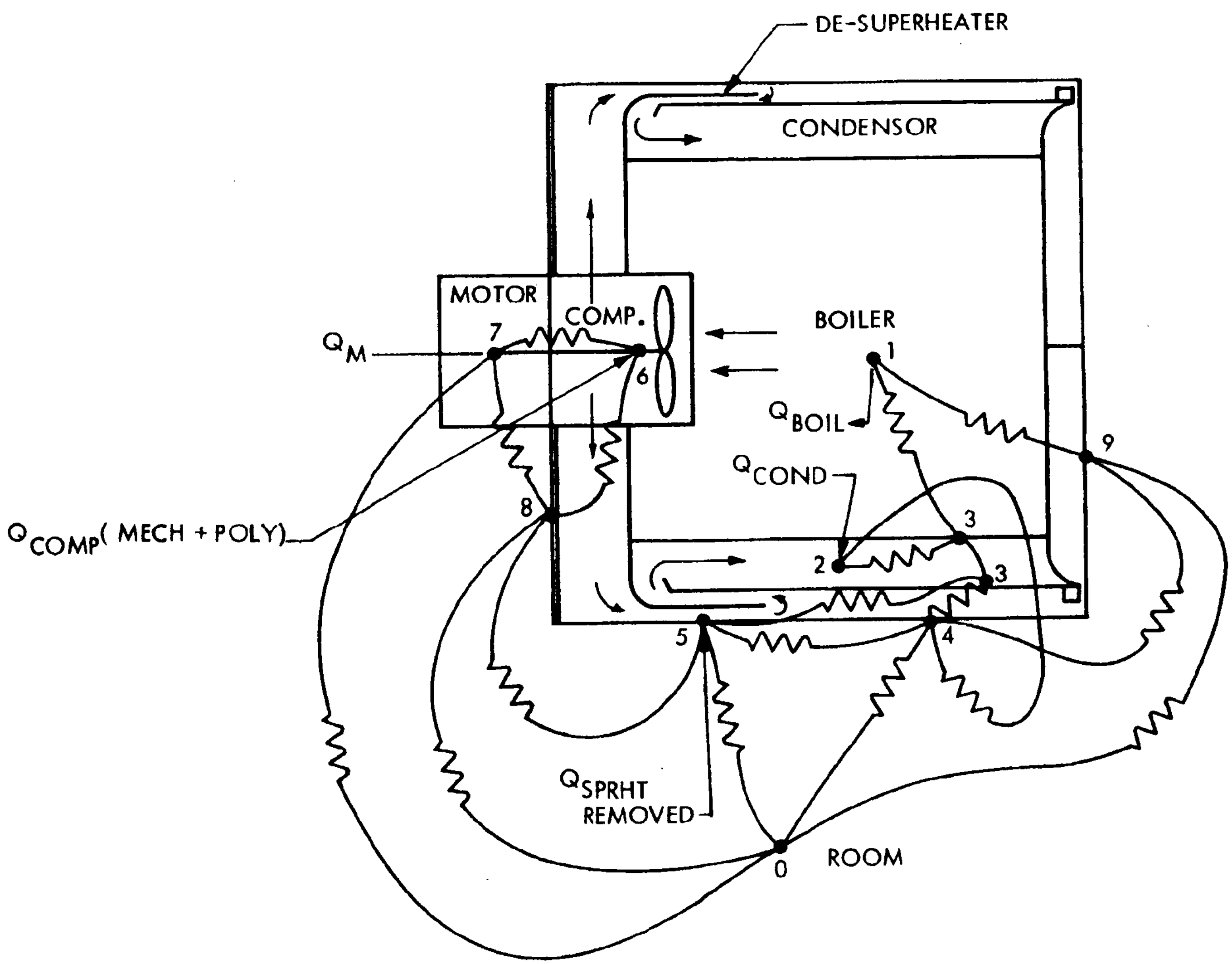


Figure 3 VCD Heat Transfer Nodal Model

The program listing (VCD 21), variable list, variable cross reference, and a sample printout are presented.

VCD21

```
100!DIMENSION MATRICES USED IN 9000
110 MAT A=ZER(9,9)
120 MAT B=ZER(9,1)
130 MAT C=ZER(9,1)
140 MAT K=ZER(20)
145 MAT E=ZER(9,9)
150 E8=.1                                              !CONV LIMIT(OVERALL)
160  DIM D(11)
200  MAT READ D(11)
210  DATA 39.6723,258.251,433.093,-9278.16,30519,-40781.2,14328.4,16050.7,
-8444.33,-8232.43,5211.99
1000!PROCESS VARIABLES INPUT
1100 PRINT "WHAT IS AMBIENT TEMP(DF)":
1110 INPUT T0
1260 PRINT "WHAT IS SOLUTE WEIGHT FRACTION  (DEC)":
1270 INPUT X
1280 PRINT "IS RECYCLE THROUGH WASTE TANK DESIRED(Y OR N)-
     N GIVES RECYCLE THROUGH RECYCLE TANK":
1290 INPUT N3
2000 ! MACHINE VARIABLES
2010 N1=1.62                                           !COMP POLY EXPONENT
2030 D1=.0142                                          !COMP DISP(CU FT/REV)
2060 A1=2.63                                           !BOILER AREA(SQ FT)
2070 G1=.07333                                         !RPM BOILER/RPM COMP
2080 D2=1                                              !BOILER DIA  (FT)
2090 F1=.00042                                         !COND MEAN FILM THK(FT)
2100 V5=.06876                                         !PURGE PUMP DISPXVOL EFF(CFM)
2110 M5=1.18E-5                               !BOILER NON COND GEN RATE(LB/MIN)
2120 M6=1E-6                                  !COND SIDE NON COND LEAK RATE(LB/MIN)
2130 Q0=34                                             !FLUID FEED PUMP HEAT(BTU/HR)
2140 V6=.328                                           !FEED PUMP FLOW(CU FT/HR)
2200!CONSTANT RESISTANCE INPUTS(BTU/HR DF)
2210 K(7)=100                                          !K45
2220 K(8)=.051                                         !K49
2230 K(10)=.296                                        !K58
2240 K(12)=.527                                        !K68
2250 K(20)=1.2                                         !K67
2300 !VARIABLE RESISTORS-INITIAL INPUTS(BTU/HR DF)
2310 K(2)=.256                                         !K19
2320 K(4)=400                                          !K24
2330 K(5)=0                                            !K35
2340 K(6)=.549                                         !K34
2350 K(9)=1.89                                         !K40
2360 K(11)=1.89                                        !K50
2370 K(14)=.882                                        !K78
2380 K(15)=1.5                                         !K70
2390 K(16)=1.5                                         !K80
2400 K(17)=.917                                        !K90
2410 K(13)=.443                                        !USED IN SPRHT REMOVAL
2420 K(18)=6.42                                        !WASTE TANK UA(BTU/HR DF)
2430 K(19)=4.56                                        !RECYCLE UA(BTU/HR DF)
2500!INITIAL CONDITIONS
2510 T6=T0              !USED IN 6000                  !SET STILL WALL=AMBIENT
2520 T4=T0                                             !INITIAL TCOND=TAMB
```

```
2530 T=T0-.001                                          !INITIAL TBOILER=TAMB-.001DF
2540 R3=3750                     !COMP RPM FOR 1ST ITERATION OF BOILER N.C.PRES
2550 E1=.7                       !COMP VOL EFF FOR 1ST ITERATION OF BOIL N.C.PRES
3000 ! NON CONDENSIBLE CALCULATION
3010! PROPERTIES ON CONDENSOR SIDE
3020 P8=EXP(16.8563-(9469.22/(T4+460)))                !P STEAM-COND(PSI)
3030 P7=M5*(T+460)*.37014/(R3*D1*E1)                   !BOILER N.C.PART PRES(PSI)
3040 P0=(M5+M6)*(T4+460)*.37014/V5                     !COND N.C. PART PRES(PSI)
3050 M4=V5*P8*100.723/(T4+460)                         !H2O FROM PURGE PUMP(LB/HR)
4000!PROPERTIES CALCULATIONS FOR FLUID IN BOILER SIDE
4020! DIFFERENTIAL HEAT OF VAPORIZATION AT T FOR 4 DF TEMP INCREMENT
4090 IF X<=0 THEN 4100 ELSE 4120
4100 L1=1
4110 GO TO 4210
4120 T1=T-2
4130 P1=EXP(16.8563-(9469.22/(T1+460)))                  !VAP PRES H20 AT T-2(PSI)
4140 GOSUB 4240
4150 P2=P1/P9                                            !VAP PRES URINE AT T-2(PSI)
4160 T1=T+2
4170 P3=EXP(16.8563-(9469.22/(T1+460)))                  !VAP PRES H20 AT T+2(PSI)
4180 GO SUB 4240
4190 P4=P3/P9                                          !VAP PRES URINE AT T+2(PSI)
4200 L1=LOG(P4/P2)/(LOG(P3/P1))                        !DIF HT VAP URINE/HT VAP H2O
4210 L=(1093.74-.567857*T)*L1                          !DIF HT VAP URINE
4230 GO TO 4340
4240!SUBROUTINE FOR VAP PRES H2O/VAP PRES URINE VS SOLUTE WGT FRACT(X)
4250 M=0
4260 FOR I=1 TO 11
4262 IF X=0 THEN P9=1 ELSE 4270
4264 GO TO 4320
4270 M1=D(I)*X^(I-1)
4280 M=M+M1
4290 NEXT I
4300 M2=M-.1145*(T1-100)    !GOOD ONLY IF X>0          !APPARENT MW URINE AT T1
4310 P9=(18*X/(M2*(1-X)))+1                            !VAP PRES H2O/VAP PRES URINE
4320 RETURN
4340 !VAP PRES URINE AT T
4350 T1=T
4360 P5=EXP(16.8563-(9469.22/(T1+460)))                  !VAP PRES H20 AT T (PSI)
4370 GO SUB 4240
4380 P6=P5/P9                                          !VAP PRES URINE@ T(PSI)
4390 V1=85.58*(T+460)/(P6*144)                         !SP VOL STEAM @ T&P BOILER
4400 R1=(.4775*X+.99325)*62.4                          !DEN LIQUID(LBM/CU FT)
4500 !VISCOSITY CALC
4510 IF X>.5 THEN 4540
4520 V2=.9*EXP(1.5*X/(1-X))                            !VISC URINE @70DF(CENTIPOISE)
4530 GO TO 4550
4540 V2=1.8*EXP(.8*X/(1-X))                            !VISC URINE @70DF(CENTIPOISE)
4550 V3=V2*3.6885*(-.0125693+46.8259/T)                !VISC URINE @ T (LBM/FT HR)
4560 S1=73.0559-133.524*X+240.376*X^2-257.478*X^3+137.82*X^4
     !SURFACE TENSION URINE @ 70DF (DYNES/CM)
4570 S2=S1*(77.8444-.0888889*T)*9.565E-7               !SURF TENSION @ T (LBF/FT)
4580 C1=1-.7*X                                         !SP HT URINE(BTU/LBM DF)
4590 K1=.197136*T^.133101                              !THER COND H2O(BTU/HR FT DF)
```

```
5000!CALCULATION OF COMPRESSOR AND MOTOR VARIABLES USING NEWTONS
      METHOD TO BALANCE RPM OF COMP WITH RPM OF MOTOR
5100 Z0=3700                                           !FIRST GUESS FOR COMP RPM
5110 !NEWTONS METHOD FOR F(Z)=0 WITH NUMERICAL APPROXIMATION FOR F'(Z)
5120 E9=.00001                                          !ERROR FOR CONVERGENCE
5130 !INITIAL GUESS FOR Z IS Z0
5140 FOR I=1 TO 20
5150 Z1=Z0+1E-5*Z0                                      !Z(I)+DZ
5160 R3=Z0
5170 GO SUB 5360
5180 Y0=Y9                                              !F(Z(I))
5182 IF Y0#0 THEN 5190
5184 Z2=Z0
5186 GO TO 5340
5190 R3=Z1
5200 GO SUB 5360
5210 Y1=Y9                                              !F(Z(I)+DZ)
5212 IF Y1#0 THEN 5220
5214 Z2=Z1
5216 GO TO 5340
5220 Z3=(Y1-Y0)/1E-5*Z0                                 !F'(Z(I))APPROX
5230 IF Z3=0 THEN 5320
5240 Z2=Z0-1E-5*Z0*(Y1/Y0-1)^-1                         !Z(I+1)
5250!TEST FOR ROOT
5260 IF ABS(Z2-Z0)<E9 AND ABS(Y0)<E9 THEN 5340
5270 Z0=Z2
5290 NEXT I
5300 PRINT "ROOT HAS NOT BEEN FOUND IN DESIRED # INTERVALS"
5310 STOP
5320 PRINT"F'(Z)=0  TRY ANOTHER GUESS FOR Z0"
5330 STOP
5340!CONTINUE
5350 GO TO 5520
5360!SUBROUTINE FOR EQUATION F(Z)=0 IN TERMS OF R3=Z;Y9=F(R3)
5370! COMPRESSOR AND MOTOR CALCULATIONS
5375 W4=.0198*R3                                        !TAER POWER(WATTS)
5380 !COMPRESSOR CALCULATIONS
5390 T2=T+460                                           !BOILER TEMP(DR)
5400 T3=T2*((P8+P0)/(P6+P7))^((N1-1)/N1)                !COMP OUTLET TEMP(DR)
5410 V4=V1*P6/(P6+P7)                                   !SP VOL BOILER MIX(CU FT/LB)
5420 R2=2.13*240*(.08636*V4*((P8+P0)-(P6+P7)))^.5           !COMP SLIP RPM
5430 E1=(R3-R2)/R3                                      !COMP VOL EFF(DEC)
5435 E2=.446-4.01E-4*(P8+P0-P6-P7)                          !COMP MECH EFF(DEC)
5440 W1=(N1/(N1-1))*(P6+P7)*(T3/T2-1)*E1*R3*D1*3.2544/E2 !WORK INTO COMP(WATTS)
5450 Q1=((1.33-N1)/(N1-1))*(T3-T2)*R3*D1*E1*5.907/V4 !POLY HT COMP REJ(WATTS)
5460 Q2=Q1+W1*(1-E2)                                    !HT REJ FROM COMP(WATTS)
5470 !MOTOR CALCULATIONS
5480 W2=(W1+W4)*84.484/R3                               !MOTOR OUTPUT TORQUE(IN LB)
5490 R4=3889-144*W2                                     !THEO MOTOR RPM
5500 Y9=R3-R4
5510 RETURN
5520!USE LAST VALUE OF Z2 FOR FINAL PROPERTIES CALCULATION
5530 R3=Z2
5540 GO SUB 5360
```

```
5560 ! MOTOR POWER CALCULATION
5570 E3=(10.66667*W2+52)/100                                !MOTOR EFF(DEC)
5580 W3=(W1+W4)/E3                                          !MOTOR INPUT POWER(WATTS)
5590 Q3=W3*(1-E3)                                           !MOTOR HEAT REJ(WATTS)
6000!SUPERHEAT CALCUALTIONS
6100 M3=60*D1*R3*E1*P6/((P6+P7)*V1)                         !MASS H20 FROM COMP(LB/HR)
6110 Q8=M3*.446*(T3-460-T4)                                 !MAX SPRHT POSSIBLE(BTU/HR)
6120 T5=(T3-460-T6)/EXP(K(13)/(M3*.446))+T6                 !T OUT OF SPRHT SECT(DF)
6130 Q4=M3*.446*(T3-460-T5)                                 !SPRHT REMOVED(BTU/HR)
6140 IF Q4>Q8 THEN Q4=Q8
6150 Q5=Q8-Q4                                               !SPRHT ADDED TO COND(BTU/HR)
6300!RECYCLE LOOP HEAT LOSSES
6310 IF N3="Y" THEN 6350
6320!RECYCLE THROUGH RECYCLE TANK
6330 T7=((V6-M3/62)*T+M3*T0/62+T0*K(19)/62)/(V6+K(19)/62)!RETURN TEMP(DF)
6340 GO TO 6370
6350!RECYCLE THROUGH WASTE TANK
6360 T7=((V6-M3/62)*T+M3*T0/62+T0*K(18)/62)/(V6+K(18)/62)!RETURN TEMP(DF)
6370!Q REMOVED FROM BOILER
6380 Q9=V6*62*(T-T7)-.33*Q0
7000!BOILER AND CONDENSOR HEAT CALCULATIONS
7100 Q6=L*M3
7110 IF M4>M3 THEN M4=M3
7200 Q7=(1093.74-.567857*T4)*(M3-M4)+Q5                     !COND HEAT(BTU/HR)
8000!HEAT TRANSFER COEFFICIENTS AND RESISTANCES
8100! BOILER COEFFICIENT
8110 N2=C1*V3/K1                                            !BOILER LIQUID PRANDTL NO
8120 A2=D2*(R3*G1*376.99)^2/2                               !BOILER ACCEL(FT/SQ HR)
8130 X2=L*.006*N2^1.2*(Q6*(4.17E8*S2/(A2*(R1-1/V1))))^.5/(A1*V3*L))^.33/C1
     !BOILING DELTA T(DF)
8140 H1=Q6/(A1*X2)                              !BOILER FILM COEFFICIENT(BTU/HR SQ FT DF)
8200! CONDENSOR COEFFICIENT
8210 H2=.197136*T4^.133101/F1                   !CONDENSOR FILM COEF(BTU/HR SQ FT DF)
8300 K(1)=H1*A1                                             !BOILER K(BTU/HR DF)=K13
8310 K(3)=H2*A1                                             !COND K(BTU/HR DF)=K23
9000!MATRIX NODAL HEAT BALANCE
9010!DEFINITION OF "A" MATRIX TERMS
9020 A(1,1)=-(K(1)+K(2))
9030 A(1,3)=K(1)
9040 A(1,9)=K(2)
9050 A(2,2)=K(3)+K(4)
9060 A(2,3)=-K(3)
9070 A(2,4)=-K(4)
9080 A(3,1)=K(1)
9090 A(3,2)=K(3)
9100 A(3,3)=-(K(3)+K(1)+K(5)+K(6))
9110 A(3,4)=K(6)
9120 A(3,5)=K(5)
9130 A(4,2)=K(4)
9140 A(4,3)=K(6)
9150 A(4,4)=-(K(7)+K(4)+K(6)+K(8)+K(9))
9155 A(4,5)=K(7)
9160 A(4,9)=K(8)
9170 A(5,3)=-K(5)
```

```
9180 A(5,4)=-K(7)
9190 A(5,5)=K(7)+K(10)+K(11)+K(5)
9200 A(5,8)=-K(10)
9210 A(6,6)=K(12)+K(20)
9215 A(6,7)=-K(20)
9220 A(6,8)=-K(12)
9225 A(7,6)=-K(20)
9230 A(7,7)=K(15)+K(14)+K(20)
9240 A(7,8)=-K(14)
9250 A(8,5)=K(10)
9260 A(8,6)=K(12)
9270 A(8,7)=K(14)
9280 A(8,8)=-(K(12)+K(10)+K(16)+K(14))
9290 A(9,1)=K(2)
9300 A(9,4)=K(8)
9310 A(9,9)=-(K(8)+K(2)+K(17))
9400 !DEFINITION OF "C" MATRIX TERMS
9410 C(1,1)=Q6+Q9-.1*W4*3.413                     !Q BOILER(BTU/HR)
9420 C(2,1)=Q7+.1*W4*3.413                        !Q CONDENSOR(BTU/HR)
9430 C(4,1)=-K(9)*T0
9440 C(5,1)=Q4+K(11)*T0                              !Q4=SPR HT REJ(BTU/HR)
9450 C(6,1)=(Q2+.8*W4)*3.413                          !Q COMP REJ(BTU/HR)
9460 C(7,1)=Q3*3.413+K(15)*T0                        !Q3=MOTOR HEAT REJ(WATTS)
9470 C(8,1)=-K(16)*T0
9480 C(9,1)=-K(17)*T0
9500! MATRIX SOLUTION
9510 MAT E=INV(A)
9520 MAT B=E*C
9600!COMPARISON OF NODAL AND THERMODYNAMIC PROPERTIES
9610 D1=T-B(1,1)
9620 D2=T4-B(2,1)
9630 IF ABS(D1)<= E8 THEN 9650
9640 GO TO 10000
9650 IF ABS(D2)<= E8 THEN 11000
10000 !UPDATE PROPERTIES
10100 T=(T+B(1,1))/2
10110 T4=(T4+B(2,1))/2
10900 GO TO 3000
11000 !CONTINUE
11200 PRINT"CONDENSATE FLOWRATE OUT(LB/HR)=":(M3-M4)
11300 PRINT"WATER FLOW FROM PURGE PUMP(LB/HR)=":M4
11400 PRINT"ELECTRICAL POWER INTO MOTOR(WATTS)=":W3
11500 PRINT "TOTAL CONDENSOR PRESSURE (PSI)=":P8+P0
11510 PRINT"CONDENSOR NON COND PART PRES(PSI)=":P0
11600 PRINT"TOTAL BOILER PRESSURE(PSI)=":P6+P7
11610 PRINT"BOILER NON COND PART PRES(PSI)=":P7
11700 PRINT "CONDENSOR TEMPERATURE(DF)=":B(1,1)
11710 PRINT"RECYCLE FLUID RETURN TEMP(DF)=":T7
11800 PRINT "BOILER TEMPERATURE(DF)=":B(2,1)
11900 PRINT "FINAL NODAL TEMPERATURES IN ORDER STARTING WITH 1"
11910 MAT PRINT B
```

Variable List - VCD 21

A1	Boiler Area (ft^2)
A2	Boiler Acceleration (ft/hr^2)
C1	Specific Heat Liquid (BTU/lbm^oF)
D1	Compressor Displacement (ft^3/rev)
D2	Boiler Diameter (ft)
E1	Compressor volumetric eff. (dec)
E2	Compressor mechanical eff. (dec)
E3	Compressor motor eff. (dec)
E8	Overall convergence limit
E9	Convergence limit in motor RPM convergence
F1	Condenser mean film thickness (ft)
G1	Boiler RPM/Comp. RPM
H1	Boiler film coefficient (BTU/hr ft^2 ^oF)
H2	Condenser film coefficient (BTU/hr ft^2 ^oF)
I	logs variable
K1	Thermal conductivity of water (BTU/hr ft ^oF)
L	Differential heat of vaporization of urine (BTU/lb)
L1	Differential ht. vap. urine/Diff ht. vap water
M	Mol Wgt mix at 100^oF
M1	Calculation variable
M2	Apparent mol. Wgt urine at T1.
M3	Mass of steam through compressor (lb/hr)
M4	Mass of water out of purge pump (lb/hr)
M5	Boiler non-condensible leak rate (lb/min)
M6	Shell non-condensible leak rate (lb/min)
N1	Compressor polytropic exponent
N2	Prandtl number of urine
N3	Constant in data input routine
O1	T-B(1)
O2	T4-B(4)
PO	Condenser non-condensible partial pres. (psi)
P1	Calculation variable for diff. ht. vap.
P2	Calculation variable for diff. ht. vap.
P3	Calculation variable for diff. ht. vap.
P4	Calculation variable for diff. ht. vap.
P5	Vap. pres. water at T boiler

P6	Vap. pres. urine at T boiler
P7	Boiler non-condensible partial pres. (psi)
P8	Condenser steam pressure (psi)
P9	Vap pres. water/vapor pres. urine
Q0	Feed pump heat into fluid (BTU/hr)
Q1	Polytropic heat rejected from compressor (watts)
Q2	heat rejected from compressor (watts)
Q3	heat rejected from motor (watts)
Q4	super heat removed (BTU/hr)
Q5	superheat added to condenser (BTU/hr)
Q6	Heat of boiling (BTU/hr)
Q7	Heat of condensing (BTU/hr)
Q8	max superheat which can be removed (BTU/hr)
Q9	heat removed in recycle loop (BTU/hr)
R1	density of urine in boiler (lb/ft^3)
R2	Slip RPM of compressor
R3	Actual RPM of compressor
R4	Theoretical Motor RPM
S1	surface tension of urine in boiler at $70^{o}F$ (dynes/cm)
S2	surface tension of urine in boiler at any T (lbm/hr)
T	Boiler temperature (^{o}F)
TO	Ambient temperature (^{o}F)
T1	Calculation variable
T2	Boiler Temperature (^{o}R)
T3	Compressor outlet temp. (^{o}R)
T4	Condenser Temp. (^{o}F)
T5	Temp. out of desuperheat section (^{o}F)
T6	Wall temperature used in desuperheat calc. (^{o}F)
T7	Fluid return temperature (^{o}F)
V1	Sp. vol. of steam in boiler (ft^3/lb)
V2	Visc of urine in boiler at $70^{o}F$ (centipoise)
V3	Visc of urine in boiler at any T (lbm/hr)

V4	sp. vol. steam plus non condensible gasses (ft^3/lb)
V5	Purge pump actual displacement (cfm)
V6	feed pump capacity (ft^3/hr)
W1	Actual work into compressor (watts)
W2	Torque out of motor (in lb)
W3	Power into motor (watts)
W4	Tare power of machine (watts)
X	Solute weight fraction (decimal)
X2	Superheat delta temperature in boiler (^oF)
Y0	Variable in compressor RPM convergence
Y1	Variable in compressor RPM convergence
X9	Variable in compressor RPM convergence
Z0	Initial guess for compressor RPM
Z1	Variable in compressor RPM convergence
Z2	Variable in compressor RPM convergence
Z3	Variable in compressor RPM convergence

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PROGRAM NAME IS: VCD21

DICTIONARY OF VARIABLES WITH LINE REFERENCES

```
VAR.--REFERENCE LINE #
NAME
A1   2060 8130 8140 8300 8310
A2   8120 8130
C1   4580 8110 8130
D1   3030 3030 5440 5450 6100
D2   2080 8120
E1   2550 3030 5430 5440 5450 6100
E2   5435 5440 5460
E3   5570 5580 5590
E8   150 9630 9650
E9   5120 5260
F1   2090 8210
G1   2070 8120
H1   8140 8300
H2   8210 8310
I    4260 4270 4290 5140 5290
K1   4590 8110
L    4210 7100 8130
L1   4100 4200 4210
M    4250 4280 4300
M1   4270 4280
M2   4300 4310
M3   6100 6110 6120 6130 6330 6360 7100 7110 7200 11200
M4   3050 7110 7200 11200 11300
M5   2110 3030 3040
M6   2120 3040
N1   2010 5400 5440 5450
N2   8110 8130
N3   1290 6310
O1   9610 9630
O2   9620 9650
P0   3040 5400 5420 5435 11500 11510
P1   4130 4150 4200
P2   4150 4200
P3   4170 4190 4200
P4   4190 4200
P5   4360 4380
P6   4380 4390 5400 5410 5420 5435 5440 6100 11600
P7   3030 5400 5410 5420 5435 5440 6100 11600 11610
P8   3020 3050 5400 5420 5435 11500
P9   4150 4190 4262 4310 4380
```

```
Q0   2130 6380
Q1   5450 5460
Q2   5460 9450
Q3   5590 9460
Q4   6130 6140 6150 9440
Q5   6150 7200
Q6   7100 8130 8140 9410
Q7   7200 9420
Q8   6110 6140 6150
Q9   6380 9410
R1   4400 8130
R2   5420 5430
R3   2540 3030 5160 5190 5375 5430 5440 5450 5480 5500
     5530 6100 8120
R4   5490 5500
S1   4560 4570
S2   4570 8130
T    2530 3030 4120 4160 4210 4350 4390 4550 4570 4590
     5390 6330 6360 6380 9610 10100
T0   1110 2510 2520 2530 6330 6360 9430 9440 9460 9470
     9480
T1   4120 4130 4160 4170 4300 4350 4360
T2   5390 5400 5440 5450
T3   5400 5440 5450 6110 6120 6130
T4   2520 3020 3040 3050 6110 7200 8210 9620 10110
T5   6120 6130
T6   2510 6120
T7   6330 6360 6380 11710
V1   4390 5410 6100 8130
V2   4520 4540 4550
V3   4550 8110 8130
V4   5410 5420 5450
V5   2100 3040 3050
V6   2140 6330 6360 6380
W1   5440 5460 5480 5580
W2   5480 5490 5570
W3   5580 5590 11400
W4   5375 5480 5580 9410 9420 9450
X    1270 4090 4262 4270 4310 4400 4510 4520 4540 4560
     4580
X2   8130 8140
Y0   5180 5182 5220 5240 5260
Y1   5210 5212 5220 5240
Y9   5180 5210 5500
Z0   5100 5150 5160 5184 5220 5240 5260 5270
Z1   5150 5190 5214
Z2   5184 5214 5240 5260 5270 5530
Z3   5220 5230
```

DICTIONARY OF ARRAYS WITH LINE REFERENCES

ARRAY--REFERENCE LINE #

```
A    110 9020 9030 9040 9050 9060 9070 9080 9090 9100
     9110 9120 9130 9140 9150 9155 9160 9170 9180 9190
     9200 9210 9215 9220 9225 9230 9240 9250 9260 9270
     9280 9290 9300 9310 9510
B    120 9520 9610 9620 10100 10110 11700 11800 11910
C    130 9410 9420 9430 9440 9450 9460 9470 9480 9520
D    160 200 4270
E    145 9510 9520
K    140 2210 2220 2230 2240 2250 2310 2320 2330 2340
     2350 2360 2370 2380 2390 2400 2410 2420 2430 6120
     6330 6360 8300 8310 9020 9030 9040 9050 9060 9070
     9080 9090 9100 9110 9120 9130 9140 9150 9155 9160
     9170 9180 9190 9200 9210 9215 9220 9225 9230 9240
     9250 9260 9270 9280 9290 9300 9310 9430 9440 9460
     9470 9480
```

CROSS REFERENCE OF LINE NUMBERS

```
LINE #   REFERENCE LINE #
3000     10900
4100     4090
4120     4090
4210     4110
4240     S4140 S4180 S4370
4270     4262
4320     4264
4340     4230
4540     4510
4550     4530
5190     5182
5220     5212
5320     5230
5340     5186 5216 5260
5360     S5170 S5200 S5540
5520     5350
6350     6310
6370     6340
9650     9630
10000    9640
11000    9650
```

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```
RUN
WHAT IS AMBIENT TEMP(DF)? 70
WHAT IS SOLUTE WEIGHT FRACTION (DEC)? .1
IS RECYCLE THROUGH WASTE TANK DESIRED(Y OR N)-        N GIVES RECYCLE THROUGH REC
TANK? Y
CONDENSATE FLOWRATE OUT(LB/HR)= 2.4495642
WATER FLOW FROM PURGE PUMP(LB/HR)= 7.9408953E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 130.81012
TOTAL CONDENSOR PRESSURE (PSI)= .66439638
CONDENSOR NON COND PART PRES(PSI)= 3.7663253E-02
TOTAL BOILER PRESSURE(PSI)= .4855614
BOILER NON COND PART PRES(PSI)= 8.68239E-05
CONDENSOR TEMPERATURE(DF)= 79.626944
RECYCLE FLUID RETURN TEMP(DF)= 76.409004
BOILER TEMPERATURE(DF)= 86.69885
FINAL NODAL TEMPERATURES IN ORDER STARTING WITH 1
 79.626944
 86.69885
 85.534231
 86.653035
 86.79777
 312.20704
 197.40896
 146.43992
 72.707355

>
```

Transient Performance Model

The transient model is similar to the steady state model, except that it includes component masses and evaluates the machine temperatures as a function of operating time. The program is set up to analyze recycle through the waste tank at a constant feed solute fraction, followed by recycle through the recycle tank at a different solute weight fraction.

Program Description

The program utilizes the same basic flow chart as the steady state program.

Data input and machine variable storage are in steps 1000-2500. Machine variables are stored in a file, and other inputs are from the terminal.

In step 2600-2700 the initial machine nodal temperatures are set equal to the ambient temperature, and the variable time increments necessary to allow converge but minimize computer time, are established.

In steps 2700-3000, the mass times specific heat of each major nodal point is stored. The motor mass is not included as it is not heavy compared to other components, and heats up rapidly, thus distributing convergence with the maximum increment size.

In steps 3000-9000 the boiler fluid properties are calculated, the compressor and motor power are balanced, superheat and recycle heat calculations are made, and the boiler and condenser heat transfer resistances are calculated. These steps are identical to those in the steady state program.

The matrix is similar to the steady state matrix except that it has constant terms representing the initial temperatures of the nodes, and the mass times specific heat of the nodes. The solution is again by matrix inversion and the result is the final temperature of the nodes at the end of the incremental time period.

After the inversion, the temperatures from the matrix are compared with the temperatures used to calculate the thermodynamic properties. If they are equal within the convergence limit the program, the cumulative time is increased and the program repeats with a new time interval. If the values are not equal the program repeats the calculation within the same time interval until they are.

When the final time is reached the program prints the final data and ends. If the recycle option is selected the program changes the solute fraction and runs until the final recycle time is reached. It then prints the data and ends.

Program Operation and Data Interpretation

The program is self documenting. Input data consists of the ambient temperature, solute weight fraction (for recycle through waste tank), basic time increment, final time (time at which recycle through the waste tank ends), and the option of low solids mode operation. If low solids mode operation is not selected the program will run with recycle only through the recycle tank.

If low solids mode operation is selected, the program requires two additional inputs. These are the final recycle time (the cumulative time at which machine operation ceases), and the recycle mode solute weight fraction (while recycle is through recycle tank). In this mode the program runs for recycle through the waste tank, and then automatically switches to operation through the recycle tank.

Machine variables are stored in steps 2000-2200, and can be changed in the program if desired. The heat transfer resistances are stored in steps 2200-2500, and all temperatures are initialized to ambient in steps 2600-2640. If initial temperatures other than ambient are desired, they must be input here.

Steps 2640-2700 are convergence statements. They control the size of the time increment in the calculations. If these are too large the program will oscillate. If oscillation occurs, either these statements or the basic time increment must be changed.

Steps 2700-3000 have the mass times specific heat of the various components. Changes can be made directly in the program.

Output is printed for each increment of time. It consists of the time, the condensate flow rate, the water flow from the purge pump, electrical power into the motor, the total condenser pressure, the total boiler pressure, the condenser temperature, the boiler temperature, the recycle fluid return temperature, and the heat removed from the boiler in the recycle loop.

The program listing (VCD T9), additional variables list, variable cross reference, and a sample run are presented.

```
100!DIMENSION MATRICES USED IN 9000
110 MAT A=ZER(9,9)
120 MAT B=ZER(9,1)
130 MAT C=ZER(9,1)
140 MAT K=ZER(20)
145 MAT E=ZER(9,9)
146 MAT M=ZER(11)
147 MAT I=ZER(9,1)
150 E8=1                                               !CONV LIMIT(OVERALL)
160  DIM D(11)
200  MAT READ D(11)
210  DATA 39.6723,258.251,433.093,-9278.16,30519,-40781.2,14328.4,16050.7,
-8444.33,-8232.43,5211.99
220 U1=0
1000!PROCESS VARIABLES INPUT
1100 PRINT "WHAT IS AMBIENT TEMP(DF)":
1110 INPUT T0
1260 PRINT "WHAT IS SOLUTE WEIGHT FRACTION (DEC)":
1270 INPUT X
1280 PRINT"WHAT IS BASIC TIME INCREMENT(HR)":
1290 INPUT I4
1300 PRINT"WHAT IS FINAL TIME(HR)":
1310 INPUT I3
1320 PRINT "IS LOW SOLIDS MODE OPTION DESIRED(Y OR N)":
1330 INPUT U2
1340 IF U2="Y" THEN 1370
1350 U1=1
1360 GO TO 2000
1370 PRINT"WHAT IS FINAL RECYCLE TIME(HR)":
1380 INPUT I5
1390 PRINT"WHAT IS RECYCLE SOLUTE WEIGHT FRACTION(DEC)":
1400 INPUT X1
2000 ! MACHINE VARIABLES
2010 N1=1.3                                            !COMP POLY EXPONENT
2030 D1=.0142                                          !COMP DISP(CU FT/REV)
2060 A1=2.63                                           !BOILER AREA(SQ FT)
2070 G1=.07333                                         !RPM BOILER/RPM COMP
2080 D2=1                                              !BOILER DIA (FT)
2090 F1=.00042                                         !COND MEAN FILM THK(FT)
2100 V5=.06876                                         !PURGE PUMP DISPXVOL EFF(CFM)
2110 M5=1.18E-5                             !BOILER NON COND GEN RATE(LB/MIN)
2120 M6=1E-6                                !COND SIDE NON COND LEAK RATE(LB/MIN)
2130 Q0=34                                             !FLUID PUMP HEAT(BTU/HR)
2140 V6=.328                                           !FEED PUMP FLOW(CU FT/HR)
2200!CONSTANT RESISTANCE INPUTS(BTU/HR DF)
2210 K(7)=100                                          !K45
2220 K(8)=.051                                         !K49
2230 K(10)=.296                                        !K58
2240 K(12)=.527                                        !K68
2250 K(20)=1.2                                         !K67
2300 !VARIABLE RESISTORS-INITIAL INPUTS(BTU/HR DF)
2310 K(2)=.256                                         !K19
2320 K(4)=400                                          !K24
2330 K(5)=0                                            !K35
```

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```
2340 K(6)=.549                                          !K34
2350 K(9)=1.89                                          !K40
2360 K(11)=1.89                                         !K50
2370 K(14)=.882                                         !K78
2380 K(15)=1.5                                          !K70
2390 K(16)=1.5                                          !K80
2400 K(17)=.917                                         !K90
2410 K(13)=.443                                         !USED IN SPRHT REMOVAL
2420 K(18)=6.42                                         !WASTE TANK UA(BTU/HR DF)
2430 K(19)=4.56                                         !RECYCLE TANK UA(BTU/HR DF)
2500!INITIAL CONDITIONS
2510 T6=T0              !USED IN 6000                   !SET STILL WALL=AMBIENT
2520 T4=T0                                              !INITIAL TCOND=TAMB
2530 T=T0 -1                                            !INITIAL TBOILER=TAMB-1DF
2540 R3=3750                    !COMP RPM FOR 1ST ITERATION OF BOILER N.C.PRES
2550 E1=.7                      !COMP VOL EFF FOR 1ST ITERATION OF BOIL N.C.PRE
2560 I2=0                                               !INITIAL TIME =0
2570 M7=0                                               !INITIAL H20 OUT = 0
2580 T7=T0
2590 N3=1
2600 !SET ALL INITIAL TEMPERATURES EQUAL TO AMBIENT
2610 FOR I= 1 TO 9
2620 I(I,1)=T0
2630 NEXT I
2640 !CONVERGENCE STATEMENTS
2642 FOR J=1 TO 100
2644 IF J<= 2 THEN I1=.001*I4
2646 IF J>2 THEN I1=.008*I4
2648 IF J>3 THEN I1=.09*I4
2650 IF J>4 THEN I1=.4*I4
2652 IF J>5 THEN I1=.5*I4
2654 IF J>6 THEN I1=1*I4
2700!MASS*CP/TIME INCREMENT(BTU/DF HR)
2710 M(1)=(.65*1+46.2*.11)/I1
2740 M(4)=10.5*.11/I1
2750 M(5)=10.5*.11/I1
2760 M(6)=48.4*.11/I1
2780 M(8)=7.1*.11/I1
2790 M(9)=7.48*.11/I1
2800 M(10)=27.5/I1                                      !WASTE TANK M*CP AT AV LIQ
2810 M(11)=23.3/I1                                      !RECYCLE TANK M*CP AT AV LI
3000 ! NON CONDENSIBLE CALCULATION
3002! LIMIT NUMBER ITERATIIONS TO 20
3004 FOR K=1 TO 20
3010! PROPERTIES ON CONDENSOR SIDE
3020 P8=EXP(16.8563-(9469.22/(T4+460)))                 !P STEAM-COND(PSI)
3030 P7=M5*(T+460)*.37014/(R3*D1*E1)                    !BOILER N.C.PART PRES(PSI)
3040 P0=(M5+M6)*(T4+460)*.37014/V5                      !COND N.C. PART PRES(PSI)
3050 M4=V5*P8*100.723/(T4+460)                          !H20 FROM PURGE PUMP(LB/HR)
4000!PROPERTIES CALCULATIONS FOR FLUID IN BOILER SIDE
4020! DIFFERENTIAL HEAT OF VAPORIZATION AT T FOR 4 DF TEMP INCREMENT
4090 IF X<=0 THEN 4100 ELSE 4120
4100 L1=1
4110 GO TO 4210
```

```
4120 T1=T-2
4130 P1=EXP(16.8563-(9469.22/(T1+460)))          !VAP PRES H20 AT T-2(PSI)
4140 GOSUB 4240
4150 P2=P1/P9                                    !VAP PRES URINE AT T-2(PSI)
4160 T1=T+2
4170 P3=EXP(16.8563-(9469.22/(T1+460)))          !VAP PRES H20 AT T+2(PSI)
4180 GO SUB 4240
4190 P4=P3/P9                                   !VAP PRES URINE AT T+2(PSI)
4200 L1=LOG(P4/P2)/(LOG(P3/P1))                 !DIF HT VAP URINE/HT VAP H2O
4210 L=(1093.74-.567857*T)*L1                   !DIF HT VAP URINE
4230 GO TO 4340
4240!SUBROUTINE FOR VAP PRES H2O/VAP PRES URINE VS SOLUTE WGT FRACT(X)
4250 M=0
4260 FOR I=1 TO 11
4262 IF X=0 THEN P9=1 ELSE 4270
4264 GO TO 4320
4270 M1=D(I)*X^(I-1)
4280 M=M+M1
4290 NEXT I
4300 M2=M-.1145*(T1-100)   !GOOD ONLY IF X>0       !APPARENT MW URINE AT T1
4310 P9=(18*X/(M2*(1-X)))+1                     !VAP PRES H2O/VAP PRES URINE
4320 RETURN
4340 !VAP PRES URINE AT T
4350 T1=T
4360 P5=EXP(16.8563-(9469.22/(T1+460)))          !VAP PRES H20 AT T (PSI)
4370 GO SUB 4240
4380 P6=P5/P9                                   !VAP PRES URINE@ T(PSI)
4390 V1=85.58*(T+460)/(P6*144)                  !SP VOL STEAM @ T&P BOILER
4400 R1=(.4775*X+.99325)*62.4                   !DEN LIQUID(LBM/CU FT)
4500 !VISCOSITY CALC
4510 IF X>.5 THEN 4540
4520 V2=.9*EXP(1.5*X/(1-X))                     !VISC URINE @70DF(CENTIPOISE)
4530 GO TO 4550
4540 V2=1.8*EXP(.8*X/(1-X))                     !VISC URINE @70DF(CENTIPOISE)
4550 V3=V2*3.6885*(-.0125693+46.8259/T)         !VISC URINE @ T (LBM/FT HR)
4560 S1=73.0559-133.524*X+240.376*X^2-257.478*X^3+137.82*X^4
     !SURFACE TENSION URINE @ 70DF (DYNES/CM)
4570 S2=S1*(77.8444-.0888889*T)*9.565E-7        !SURF TENSION @ T (LBF/FT)
4580 C1=1-.7*X                                  !SP HT URINE(BTU/LBM DF)
4590 K1=.197136*T^.133101                       !THER COND H2O(BTU/HR FT DF)
4600!PRINTOUT OF VARIABLES
5000!CALCULATION OF COMPRESSOR AND MOTOR VARIABLES USING NEWTONS
     METHOD TO BALANCE RPM OF COMP WITH RPM OF MOTOR
5100 Z0=3700                                    !FIRST GUESS FOR COMP RPM
5110 !NEWTONS METHOD FOR F(Z)=0 WITH NUMERICAL APPROXIMATION FOR F'(Z)
5120 E9=.00001                                  !ERROR FOR CONVERGENCE
5130 !INITIAL GUESS FOR Z IS Z0
5140 FOR I=1 TO 20
5150 Z1=Z0+1E-5*Z0                              !Z(I)+DZ
5160 R3=Z0
5170 GO SUB 5360
5180 Y0=Y9                                      !F(Z(I))
5182 IF Y0=0 THEN 5190
5184 Z2=Z0
```

```
5186 GO TO 5340
5190 R3=Z1
5200 GO SUB 5360
5210 Y1=Y9                                               !F(Z(I)+DZ)
5212 IF Y1#0 THEN 5220
5214 Z2=Z1
5216 GO TO 5340
5220 Z3=(Y1-Y0)/1E-5*Z0                                  !F'(Z(I))APPROX
5230 IF Z3=0 THEN 5320
5240 Z2=Z0-1E-5*Z0*(Y1/Y0-1)^-1                          !Z(I+1)
5250!TEST FOR ROOT
5260 IF ABS(Z2-Z0)<E9 AND ABS(Y0)<E9 THEN 5340
5270 Z0=Z2
5280 !!!!!PRINT "Z2=":Z2;"Y0=":Y0
5290 NEXT I
5300 PRINT "ROOT HAS NOT BEEN FOUND IN DESIRED # INTERVALS"
5310 STOP
5320 PRINT"F'(Z)=0  TRY ANOTHER GUESS FOR Z0"
5330 STOP
5340!CONTINUE
5350 GO TO 5520
5360!SUBROUTINE FOR EQUATION F(Z)=0 IN TERMS OF R3=Z!Y9=F(R3)
5370! COMPRESSOR AND MOTOR CALCULATIONS
5375 W4=.0198*R3                                        !TAER POWER(WATTS)
5380 !COMPRESSOR CALCULATIONS
5390 T2=T+460                                           !BOILER TEMP(DR)
5400 T3=T2*((P8+P0)/(P6+P7))^((N1-1)/N1)                !COMP OUTLET TEMP(DR)
5410 V4=V1*P6/(P6+P7)                                   !SP VOL BOILER MIX(CU FT/LB)
5420 R2=2.13*240*(.08636*V4*((P8+P0)-(P6+P7)))^.5          !COMP SLIP RPM
5430 E1=(R3-R2)/R3                                      !COMP VOL EFF(DEC)
5435 E2=.446-4.01E-4*(P8+P0-P6-P7)                        !COMP MECH EFF(DEC)
5440 W1=(N1/(N1-1))*(P6+P7)*(T3/T2-1)*E1*R3*D1*3.2544/E2 !WORK INTO COMP(WATTS
5450 Q1=((1.33-N1)/(N1-1))*(T3-T2)*R3*D1*E1*5.907/V4 !POLY HT COMP REJ(WATTS)
5460 Q2=Q1+W1*(1-E2)                                    !HT REJ FROM COMP(WATTS)
5470 !MOTOR CALCULATIONS
5480 W2=(W1+W4)*84.484/R3                               !MOTOR OUTPUT TORQUE(IN LB)
5490 R4=3889-144*W2                                     !THEO MOTOR RPM
5500 Y9=R3-R4
5510 RETURN
5520!USE LAST VALUE OF Z2 FOR FINAL PROPERTIES CALCULATION
5530 R3=Z2
5540 GO SUB 5360
5560 ! MOTOR POWER CALCULATION
5570 E3=(10.66667*W2+52)/100                              !MOTOR EFF(DEC)
5580 W3=(W1+W4)/E3                                      !MOTOR INPUT POWER(WATTS)
5590 Q3=W3*(1-E3)                                       !MOTOR HEAT REJ(WATTS)
6000!SUPERHEAT CALCUALTIONS
6100 M3=60*D1*R3*E1*P6/((P6+P7)*V1)                     !MASS H20 FROM COMP(LB/HR)
6110 Q8=M3*.446*(T3-460-T4)                             !MAX SPRHT POSSIBLE(BTU/HR)
6120 T5=(T3-460-T6)/EXP(K(13)/(M3*.446))+T6             !T OUT OF SPRHT SECT(DF)
6130 Q4=M3*.446*(T3-460-T5)                             !SPRHT REMOVED(BTU/HR)
6140 IF Q4>Q8 THEN Q4=Q8
6150 Q5=Q8-Q4                                           !SPRHT ADDED TO COND(BTU/HR
6300 !RECYCLE LOOP HEAT LOSSES
```

```
6310 IF N3=1 THEN 6360
6320 !RECYCLE THROUGH RECYCLE TANK
6330 !TANK EXIT TEMP(DF)
6340 T7=((V6-M3/62)*62*T+(M3/62)*62*T0+K(19)*T0-T7*(V6*62/2+K(19)/2-M(11)))
/(V6*62/2+K(19)/2+M(11))
6345 PRINT"RECYCLE TANK EXIT TEMP(DF)=":T7
6350 GO TO 6380
6360!RECYCLE THROUGH WASTE TANK
6370 T7=((V6-M3/62)*62*T+(M3/62)*62*T0+K(18)*T0-T7*(V6*62/2+K(18)/2-M(10)))
/(V6*62/2+K(18)/2+M(10))
6380!Q REMOVED FROM BOILER
6390 Q9=V6*62*(T-T7)-.33*Q0
7000!BOILER AND CONDENSOR HEAT CALCULATIONS
7100 Q6=L*M3                                    !BOILER HEAT(BTU/HR)
7110 IF M4>M3 THEN M4=M3
7200 Q7=(1093.74-.567857*T4)*(M3-M4)+Q5         !COND HEAT(BTU/HR)
8000!HEAT TRANSFER COEFFICIENTS AND RESISTANCES
8100! BOILER COEFFICIENT
8110 N2=C1*V3/K1                                !BOILER LIQUID PRANDTL NO
8120 A2=D2*(R3*61*376.99)^2/2                   !BOILER ACCEL(FT/SQ HR)
8130 X2=L*.006*N2^1.2*(Q6*(4.17E8*S2/(A2*(R1-1/V1)))^.5/(A1*V3*L))^.33/C1
    !BOILING DELTA T(DF)
8140 H1=Q6/(A1*X2)                     !BOILER FILM COEFFICIENT(BTU/HR SQ FT DF)
8200! CONDENSOR COEFFICIENT
8210 H2=.197136*T4^.133101/F1         !CONDENSOR FILM COEF(BTU/HR SQ FT DF)
8300 K(1)=H1*A1                                 !BOILER K(BTU/HR DF)=K13
8310 K(3)=H2*A1                                 !COND K(BTU/HR DF)=K23
9000!MATRIX NODAL HEAT BALANCE
9010!DEFINITION OF "A" MATRIX TERMS
9020 A(1,1)=-(K(1)+K(2)+2*M(1))
9030 A(1,3)=K(1)
9040 A(1,9)=K(2)
9050 A(2,2)=K(3)+K(4)
9060 A(2,3)=-K(3)
9070 A(2,4)=-K(4)
9080 A(3,1)=K(1)
9090 A(3,2)=K(3)
9100 A(3,3)=-(K(3)+K(1)+K(5)+K(6))
9110 A(3,4)=K(6)
9120 A(3,5)=K(5)
9130 A(4,2)=K(4)
9140 A(4,3)=K(6)
9150 A(4,4)=-(K(7)+K(4)+K(6)+K(8)+K(9)+2*M(4))
9155 A(4,5)=K(7)
9160 A(4,9)=K(8)
9170 A(5,3)=-K(5)
9180 A(5,4)=-K(7)
9190 A(5,5)=K(7)+K(10)+K(11)+K(5)+2*M(5)
9200 A(5,8)=-K(10)
9210 A(6,6)=K(12)+2*M(6)+K(20)
9215 A(6,7)=-K(20)
9220 A(6,8)=-K(12)
9225 A(7,6)=-K(20)
9230 A(7,7)=K(15)+K(14)+K(20)
```

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9240 A(7,8)=-K(14)
9250 A(8,5)=K(10)
9260 A(8,6)=K(12)
9270 A(8,7)=K(14)
9280 A(8,8)=-(K(12)+K(10)+K(16)+K(14)+2*M(8))
9290 A(9,1)=K(2)
9300 A(9,4)=K(8)
9310 A(9,9)=-(K(8)+K(2)+K(17)+2*M(9))
9400 !DEFINITION OF "C" MATRIX TERMS
9410 C(1,1)=(K(1)+K(2)-2*M(1))*I(1,1)-K(1)*I(3,1)-K(2)*I(9,1)+2*(Q6+Q9-.1*
W4*3.413)
9420 C(2,1)=Q7+.1*W4*3.413
9430 C(3,1)=0
9440 C(4,1)=-2*K(9)*T0-K(4)*I(2,1)-K(6)*I(3,1)+(K(7)+K(4)+K(6)+K(8)+K(9)
     -2*M(4))*I(4,1)-K(7)*I(5,1)-K(8)*I(9,1)
9450 C(5,1)=2*Q4+2*K(11)*T0+K(5)*I(3,1)+K(7)*I(4,1)-(K(7)+K(10)+K(11)+K(5)
     -2*M(5))*I(5,1)+K(10)*I(8,1)
9460 C(6,1)=2*(Q2+.8*W4)*3.413-(K(12)+K(20)-2*M(6))*I(6,1)+K(12)*I(8,1)+
K(20)*I(7,1)
9470 C(7,1)=Q3*3.413+K(15)*T0
9480 C(8,1)=-2*K(16)*T0-K(10)*I(5,1)-K(12)*I(6,1)-K(14)*I(7,1)+(K(12)
     +K(10)+K(16)+K(14)-2*M(8))*I(8,1)
9490 C(9,1)=-2*K(17)*T0-K(2)*I(1,1)-K(8)*I(4,1)+(K(8)+K(2)+K(17)-2*M(9)
     )*I(9,1)
9500! MATRIX SOLUTION
9510 MAT E=INV(A)
9520 MAT B=E*C
9600!COMPARISON OF NODAL AND THERMODYNAMIC PROPERTIES
9610 D1=T-(B(1,1)+I(1,1))/2
9620 D2=T4-(B(2,1)+I(2,1))/2
9630 IF ABS(D1)<= E8 THEN 9650
9640 GO TO 10000
9650 IF ABS(D2)<= E8 THEN 11000
10000 !UPDATE PROPERTIES
10100 T=(B(1,1)+I(1,1))/2
10110 T4=(B(2,1)+I(2,1))/2
10900 NEXT K
10910 PRINT"MAX NUMBER OF ITERATIONS EXCEEDED IN THERMO-NODAL BALANCE"
10920 STOP
11000 !CONTINUE
11200 PRINT"CONDENSATE FLOWRATE OUT(LB/HR)=":(M3-M4)
11300 PRINT"WATER FLOW FROM PURGE PUMP(LB/HR)=":M4
11400 PRINT"ELECTRICAL POWER INTO MOTOR(WATTS)=":W3
11500 PRINT "TOTAL CONDENSOR PRESSURE (PSI)=":P8+P0
11600 PRINT"TOTAL BOILER PRESSURE(PSI)=":P6+P7
11700 PRINT "CONDENSOR TEMPERATURE(DF)=":B(2,1)
11800 PRINT "BOILER TEMPERATURE(DF)=":B(1,1)
11810 PRINT"RECYCLE FLUID EXIT TEMP(DF)=":T7
11820 PRINT"Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=":Q9
11900 I2=I2+I1
11910 PRINT"TIME=":I2
11912 M7=M7+(M3-M4)*I1                              !H2O OUT(TOTAL) (LB)
11914 PRINT "TOTAL CONDENSATE OUT(LB)=":M7
11920 MAT PRINT B
```

```
11930 IF I2>=(I3-I1) THEN 12000
11940 FOR I=1 TO 9
11950 I(I,1)=B(I,1)
11960 NEXT I
11970 NEXT J
12000 IF U1#0 THEN 13000
12100 U1=1
12200 I3=I5
12300 X=X1
12310 N3=0
12320 T7=T0
12400 GO TO 2640
13000 END
```

O2	9620 9650
P0	3040 5400 5420 5435 11500
P1	4130 4150 4200
P2	4150 4200
P3	4170 4190 4200
P4	4190 4200
P5	4360 4380
P6	4380 4390 5400 5410 5420 5435 5440 6100 11600
P7	3030 5400 5410 5420 5435 5440 6100 11600
P8	3020 3050 5400 5420 5435 11500
P9	4150 4190 4262 4310 4380
Q0	2130 6390
Q1	5450 5460
Q2	5460 9460
Q3	5590 9470
Q4	6130 6140 6150 9450
Q5	6150 7200
Q6	7100 8130 8140 9410
Q7	7200 9420
Q8	6110 6140 6150
Q9	6390 9410 11820
R1	4400 8130
R2	5420 5430
R3	2540 3030 5160 5190 5375 5430 5440 5450 5480 5500
	5530 6100 8120
R4	5490 5500
S1	4560 4570
S2	4570 8130
T	2530 3030 4120 4160 4210 4350 4390 4550 4570 4590
	5390 6340 6370 6390 9610 10100
T0	1110 2510 2520 2530 2580 2620 6340 6370 9440 9450
	9470 9480 9490 12320
T1	4120 4130 4160 4170 4300 4350 4360
T2	5390 5400 5440 5450
T3	5400 5440 5450 6110 6120 6130
T4	2520 3020 3040 3050 6110 7200 8210 9620 10110
T5	6120 6130
T6	2510 6120
T7	2580 6340 6345 6370 6390 11810 12320
U1	220 1350 12000 12100
U2	1330 1340
V1	4390 5410 6100 8130
V2	4520 4540 4550
V3	4550 8110 8130
V4	5410 5420 5450
V5	2100 3040 3050
V6	2140 6340 6370 6390
W1	5440 5460 5480 5580
W2	5480 5490 5570
W3	5580 5590 11400
W4	5375 5480 5580 9410 9420 9460
X	1270 4090 4262 4270 4310 4400 4510 4520 4540 4560
	4580 12300
X1	1400 12300

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X2   8130 8140
Y0   5180 5182 5220 5240 5260
Y1   5210 5212 5220 5240
Y9   5180 5210 5500
Z0   5100 5150 5160 5184 5220 5240 5260 5270
Z1   5150 5190 5214
Z2   5184 5214 5240 5260 5270 5530
Z3   5220 5230
```

DICTIONARY OF ARRAYS WITH LINE REFERENCES

```
ARRAY--REFERENCE LINE #
A    110 9020 9030 9040 9050 9060 9070 9080 9090 9100
     9110 9120 9130 9140 9150 9155 9160 9170 9180 9190
     9200 9210 9215 9220 9225 9230 9240 9250 9260 9270
     9280 9290 9300 9310 9510
B    120 9520 9610 9620 10100 10110 11700 11800 11920
     11950
C    130 9410 9420 9430 9440 9450 9460 9470 9480 9490
     9520
D    160 200 4270
E    145 9510 9520
I    147 2620 9410 9440 9450 9460 9480 9490 9610 9620
     10100 10110 11950
K    140 2210 2220 2230 2240 2250 2310 2320 2330 2340
     2350 2360 2370 2380 2390 2400 2410 2420 2430 6120
     6340 6370 8300 8310 9020 9030 9040 9050 9060 9070
     9080 9090 9100 9110 9120 9130 9140 9150 9155 9160
     9170 9180 9190 9200 9210 9215 9220 9225 9230 9240
     9250 9260 9270 9280 9290 9300 9310 9410 9440 9450
     9460 9470 9480 9490
M    146 2710 2740 2750 2760 2780 2790 2800 2810 6340
     6370 9020 9150 9190 9210 9280 9310 9410 9440 9450
     9460 9480 9490
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CROSS REFERENCE OF LINE NUMBERS

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LINE #   REFERENCE LINE #
1370     1340
2000     1360
2640     12400
4100     4090
4120     4090
4210     4110
4240     S4140 S4180 S4370
4270     4262
4320     4264
4340     4230
4540     4510
4550     4530
5190     5182
```

5220	5212
5320	5230
5340	5186 5216 5260
5360	S5170 S5200 S5540
5520	5350
6360	6310
6380	6350
9650	9630
10000	9640
11000	9650
12000	11930
13000	12000

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?UN
JHAT IS AMBIENT TEMP(DF)? 70
JHAT IS SOLUTE WEIGHT FRACTION (DEC)? .1
JHAT IS BASIC TIME INCREMENT(HR)? 1
JHAT IS FINAL TIME(HR)? 6
 S LOW SOLIDS MODE OPTION DESIRED(Y OR N)? N

:ONDENSATE FLOWRATE OUT(LB/HR)= 2.266906
JATER FLOW FROM PURGE PUMP(LB/HR)= 5.0393149E-03
:LECTRICAL POWER INTO MOTOR(WATTS)= 118.45896
'OTAL CONDENSOR PRESSURE (PSI)= .42359876
'OTAL BOILER PRESSURE(PSI)= .3517914
:ONDENSOR TEMPERATURE(DF)= 73.547216
:OILER TEMPERATURE(DF)= 69.694824
'ECYCLE FLUID EXIT TEMP(DF)= 69.999244
 REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=-14.334156
 IME= 1E-03
 OTAL CONDENSATE OUT(LB)= 2.266906E-03
 69.694824
 73.547216
 72.993163
 70.506069
 70.02784
 70.045981
 99.380077
 70.016577
 69.999968

ONDENSATE FLOWRATE OUT(LB/HR)= 2.0212456
ATER FLOW FROM PURGE PUMP(LB/HR)= 5.3585241E-03
LECTRICAL POWER INTO MOTOR(WATTS)= 121.62066
OTAL CONDENSOR PRESSURE (PSI)= .44975384
OTAL BOILER PRESSURE(PSI)= .34892644
ONDENSOR TEMPERATURE(DF)= 73.71733
OILER TEMPERATURE(DF)= 69.533886
ECYCLE FLUID EXIT TEMP(DF)= 69.998881
 REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=-19.267905
IME= 2E-03
OTAL CONDENSATE OUT(LB)= 4.2881515E-03
69.533886
73.71733
73.15831
71.3646
70.112202
70.096507
99.071422
70.049521
69.999906
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CONDENSATE FLOWRATE OUT(LB/HR)= 1.8858028
WATER FLOW FROM PURGE PUMP(LB/HR)= 5.4678461E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 122.71868
TOTAL CONDENSOR PRESSURE (PSI)= .45873262
TOTAL BOILER PRESSURE(PSI)= .34360826
CONDENSOR TEMPERATURE(DF)= 75.008566
BOILER TEMPERATURE(DF)= 68.837632
RECYCLE FLUID EXIT TEMP(DF)= 69.992251
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=-28.405452
TIME= 1E-02
TOTAL CONDENSATE OUT(LB)= 1.9374574E-02
 68.837632
 75.008566
 74.222935
 74.258457
 71.555004
 70.503656
 99.132481
 70.310679
 69.999279

CONDENSATE FLOWRATE OUT(LB/HR)= 1.7110569
WATER FLOW FROM PURGE PUMP(LB/HR)= 5.6575666E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 123.99288
TOTAL CONDENSOR PRESSURE (PSI)= .47433961
TOTAL BOILER PRESSURE(PSI)= .3377088
CONDENSOR TEMPERATURE(DF)= 76.264095
BOILER TEMPERATURE(DF)= 68.960269
RECYCLE FLUID EXIT TEMP(DF)= 69.868587
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=-36.31942
TIME= 1E-01
TOTAL CONDENSATE OUT(LB)= .17336969
 68.960269
 76.264095
 75.393804
 76.449886
 77.672379
 75.093957
 101.17346
 73.077124
 69.998466

CONDENSATE FLOWRATE OUT(LB/HR)= 1.8094549
WATER FLOW FROM PURGE PUMP(LB/HR)= 5.9947222E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 124.9868
TOTAL CONDENSOR PRESSURE (PSI)= .50215093
TOTAL BOILER PRESSURE(PSI)= .3583558
CONDENSOR TEMPERATURE(DF)= 78.92203
BOILER TEMPERATURE(DF)= 72.334361
RECYCLE FLUID EXIT TEMP(DF)= 70.055932
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)=-4.3462618
TIME= .5
TOTAL CONDENSATE OUT(LB)= .89715164
 72.334361
 78.92203
 78.094048
 78.635217
 77.436305
 94.799216
 109.80941
 [illegible]
 70.205383
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CONDENSATE FLOWRATE OUT(LB/HR)= 1.9748
WATER FLOW FROM PURGE PUMP(LB/HR)= 6.4435195E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 126.20801
TOTAL CONDENSOR PRESSURE (PSI)= .5393155
TOTAL BOILER PRESSURE(PSI)= .38869903
CONDENSOR TEMPERATURE(DF)= 80.178031
BOILER TEMPERATURE(DF)= 72.98733
RECYCLE FLUID EXIT TEMP(DF)= 71.460686
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 16.502328
TIME= 1
TOTAL CONDENSATE OUT(LB)= 1.8845516
 72.98733
 80.178031
 79.200724
 80.304968
 81.317764
 117.64516
 119.03136
 89.137107
 70.609689

CONDENSATE FLOWRATE OUT(LB/HR)= 2.0742673
WATER FLOW FROM PURGE PUMP(LB/HR)= 6.7655533E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 127.11247
TOTAL CONDENSOR PRESSURE (PSI)= .56607957
TOTAL BOILER PRESSURE(PSI)= .40909431
CONDENSOR TEMPERATURE(DF)= 81.908341
BOILER TEMPERATURE(DF)= 75.193475
RECYCLE FLUID EXIT TEMP(DF)= 72.561335
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 25.444687
TIME= 2
TOTAL CONDENSATE OUT(LB)= 3.958819
 75.193475
 81.908341
 80.953719
 81.666254
 80.659813
 157.359
 135.04843
 100.80106
 71.209877

CONDENSATE FLOWRATE OUT(LB/HR)= 2.148298
WATER FLOW FROM PURGE PUMP(LB/HR)= 6.9819026E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 127.69478
TOTAL CONDENSOR PRESSURE (PSI)= .58410381
TOTAL BOILER PRESSURE(PSI)= .42341221
CONDENSOR TEMPERATURE(DF)= 82.084075
BOILER TEMPERATURE(DF)= 74.914885
RECYCLE FLUID EXIT TEMP(DF)= 73.383101
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 29.906723
TIME= 3
TOTAL CONDENSATE OUT(LB)= 6.107117
 74.914885
 82.084075
 81.032756
 82.19584
 83.165304
 189.9345
 148.18837
 [illegible]
 71.503621
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CONDENSATE FLOWRATE OUT(LB/HR)= 2.1482973
WATER FLOW FROM PURGE PUMP(LB/HR)= 6.9819026E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 127.69479
TOTAL CONDENSOR PRESSURE (PSI)= .58410381
TOTAL BOILER PRESSURE(PSI)= .42341198
CONDENSOR TEMPERATURE(DF)= 82.646677
BOILER TEMPERATURE(DF)= 75.87633
RECYCLE FLUID EXIT TEMP(DF)= 73.57286
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 26.047802
TIME= 4
TOTAL CONDENSATE OUT(LB)= 8.2554143
 75.87633
 82.646677
 81.653779
 82.434144
 81.554253
 216.47311
 158.98788
 118.03436
 71.621343

CONDENSATE FLOWRATE OUT(LB/HR)= 2.1864278
WATER FLOW FROM PURGE PUMP(LB/HR)= 7.1073773E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 128.04192
TOTAL CONDENSOR PRESSURE (PSI)= .59457284
TOTAL BOILER PRESSURE(PSI)= .43136256
CONDENSOR TEMPERATURE(DF)= 82.83318
BOILER TEMPERATURE(DF)= 75.688071
RECYCLE FLUID EXIT TEMP(DF)= 73.906649
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 30.744553
TIME= 5
TOTAL CONDENSATE OUT(LB)= 10.441842
 75.688071
 82.83318
 81.76862
 82.925441
 83.836748
 238.23409
 167.77122
 124.367
 71.720583

CONDENSATE FLOWRATE OUT(LB/HR)= 2.1864277
WATER FLOW FROM PURGE PUMP(LB/HR)= 7.1073773E-03
ELECTRICAL POWER INTO MOTOR(WATTS)= 128.04192
TOTAL CONDENSOR PRESSURE (PSI)= .59457284
TOTAL BOILER PRESSURE(PSI)= .43136255
CONDENSOR TEMPERATURE(DF)= 83.199046
BOILER TEMPERATURE(DF)= 76.390327
RECYCLE FLUID EXIT TEMP(DF)= 73.999315
Q REMOVED FROM BOILER IN RECYCLE LOOP(BTU/HR)= 28.860096
TIME= 6
TOTAL CONDENSATE OUT(LB)= 12.62827
 76.390327
 83.199046
 82.184548
 83.013147
 82.241887
 255.96336
 174.98765
 [illegible]
 71.791307
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Reference

1. Composition and Concentrative Properties of Human Urine; NASA Report DAC-61125-F1, McDonnell Douglas Astronautics Co., Huntington Beach, California 1970